EXPLORING THE ROLE OF THE ELECTRONIC FRAILTY INDEX (EFI) IN IDENTIFYING VULNERABLE OLDER ADULTS IN A HEALTHCARE SETTING

by

Kristin M. Lenoir, MPH

A dissertation submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Doctor in Philosophy in
Health Services Research

Charlotte

2024

Approved by:

____
Dr. Rajib Paul

____
Dr. Michael Dulin

____
Dr. Kathryn E. Callahan

____
Dr. Julian Montoro-Rodriguez

ABSTRACT

KRISTIN M. LENIOR. Exploring the Role of the Electronic Frailty Index(eFI) in Identifying Vulnerable Older Adults in a Healthcare Setting
(Under the direction of DR. RAJIB PAUL)

Healthcare organizations play a key role in supporting health for a growing population of older adults. With the emergence of electronic health records, routinely collected data can be leveraged to identify vulnerable older adults more easily. Healthcare organizations can employ risk stratification, interventions, population management strategies, and community partnerships to enhance health and care for high-risk populations. Frailty, an internationally recognized indicator of vulnerability associated with numerous adverse outcomes, has received attention as a viable target for intervention, as it provides a multidimensional quantitative summary of an individual's health status. This dissertation comprises three studies presented with a three-manuscript model that examine how structured data from electronic medical records might be used to identify older adults with an elevated risk of experiencing adverse events. The first manuscript explores the joint association of frailty and neighborhood disadvantage with emergency and inpatient utilization and considers how area-level variables may contribute to recognizing older adults with unmet needs across functional, medical, and social domains. The second manuscript leverages longitudinal frailty measures to explore frailty transitions in a unique healthcare context to inform strategies that may prevent or delay progression to frailty or even reverse frailty. The third manuscript considers how rural residence modifies the associations between frailty state transitions and individual-level predisposing and need factors as well as contextual-level predisposing factors.

ACKNOWLEDGMENTS

I would like to extend my deepest gratitude to those who have supported me throughout this journey. First and foremost, I would like to thank my chair, Rajib Paul, for your invaluable guidance, unwavering support, and exceptional assistance. I am profoundly grateful to my committee member, Kathryn Callahan, whose mentorship and encouragement have been pivotal to my academic growth. Your belief in my abilities has helped me navigate the challenges of this endeavor. Your expertise and insights have been instrumental in shaping this work. I would like to thank my committee members, Michael Dulin and Julian Montoro-Rodriguez, for their guidance and constructive feedback.

I would also like to acknowledge my mentors, Nicholas Pajewski and Brian Wells, whose wisdom, patience, and continuous support have been a source of motivation and strength. Additionally, I extend my sincere thanks to my teachers and friends, whose encouragement and companionship have been invaluable.

Finally, I wish to express my heartfelt appreciation to my family. To Sandra and Michael Lease, thank you for your unconditional love and support. To my partner, Brandon Lenoir, thank you for your understanding, patience, and encouragement during this journey. To Remi Lenoir, thank you for bringing joy and balance into my life.

This accomplishment would not have been possible without each of you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADI	Area Deprivation Index
AHWFB	Atrium Health Wake Forest Baptist
AIC	Akaike Information Criterion
BMHSU	Behavioral Model of Health Service Use
CCI	Charlson Comorbidity Index
CHF	Congestive Heart Failure
CI	Cofidence Interval
COPD	Chronic Obstructive Pulmonary Disease
CVD	Cerebrovascular Disease
ED	Emergency Department
eFI	electronic Frailty Index
EHR	Electronic Health Record
EMR	Electronic Medical Record
GEOID	Geiographic Identifier
HR	Hazard Ratio
ICD-10	International Classification of Diseases Tenth Revision
ICE	Index of Concentration at the Extremes
INT	Interaction
IQR	Interquartile Range
RERI	Relative Excess Risk due to Interaction
SDoH	Social Determinants of Health
U.S.	United States

CHAPTER 1: INTRODUCTION

Older adults

As the population aged 65 years and older grows in the United States, healthcare organizations face challenges in meeting an increased need for chronic disease management, complex care, and healthcare resource consumption (Demiris et al. 2020; Rowe, Fulmer, and Fried 2016). Risk stratification and population management strategies are critical to providing effective and equitable care for the growing population of older adults in the United States (Coran, Schario, and Pronovost 2022). Leveraging accessible measures using electronic medical records (EMRs) could prove valuable in identifying older adults at an elevated risk for experiencing adverse events, such as high-burden and high-cost healthcare utilization or frailty development, enabling prompt interventions to potentially avert these events. Thus, healthcare organizations can play a key role in leveraging their data to support the health of older adults.

In this three-manuscript dissertation model, I propose to expand upon the extant literature by examining how an electronic Frailty Index (eFI) can facilitate screening for vulnerable older adults in a large healthcare system in the southeast United States. I explore the value of integrating social and structural determinants of health that can be derived from routinely collected EMR data and these factors' associations with healthcare utilization and frailty state transitions. The underlying context for this work is frailty's established independent association with a host of adverse outcomes, including mortality, injurious falls, and emergency and inpatient healthcare utilization (Bandeen-Roche et al. 2015; Ferri-Guerra et al. 2020; Han et al. 2019; Pajewski et al. 2019; Romero-Ortuno and Kenny 2012). Further exploring frailty's development and relationship with modifiable, social, and structural factors can help us identify vulnerable subsets of older adults, establish critical targets for intervention, and inform resource planning and population management strategies to provide effective healthcare and to support positive health outcomes for older adults.

Frailty

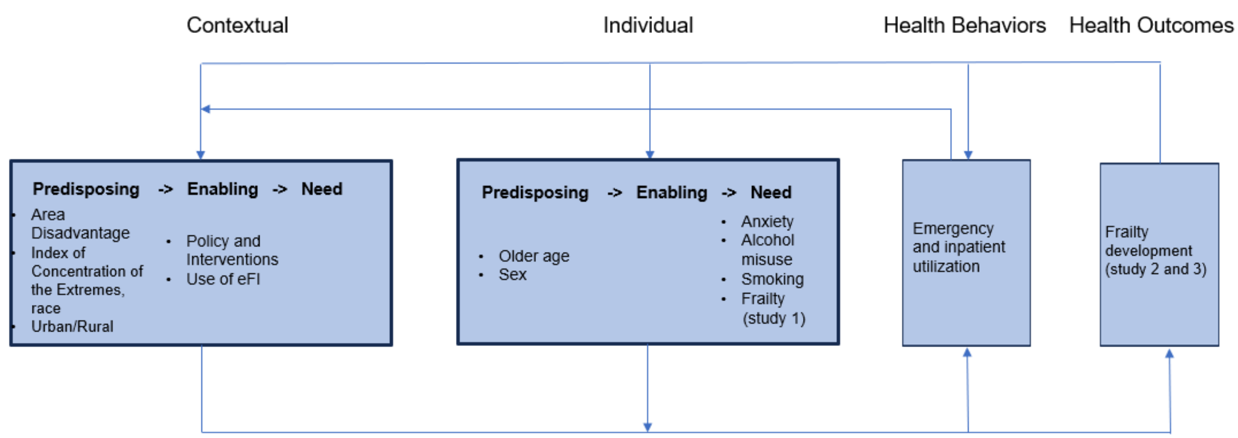
Frailty is an age-related biological process resulting in a decrease in physiologic and functional reserve, which leads to increased vulnerability and elevated risk of adverse health outcomes (Clegg et al. 2013), such as mortality, falls, and disability (Bandeen-Roche et al. 2015; Han et al. 2019; Pajewski et al. 2019; Romero-Ortuno and Kenny 2012). Frailty further risk-stratifies a population of vulnerable older adults beyond age and multi-morbidity (Bandeen-Roche et al. 2015) and has emerged as an international target for screening in healthcare (Lim et al. 2022; Muscedere et al. 2016; National Health Service England 2017). Frailty can be operationalized using routine data captured in the EMR as an electronic Frailty Index (eFI) that quantifies an accumulation of deficits (Pajewski et al. 2019), which has been validated in healthcare systems across several countries (Clegg et al. 2016; Kim et al. 2022; Lim et al. 2022; Muscedere et al. 2016; National Health Service England 2017; Pajewski et al. 2019). . The eFI is a continuous measure that has been calculated for patients 55 and older at Atrium Health Wake Forest Baptist (AHWFB) since 2019, and can be categorized into the following frailty states: fit ($eFI \leq 0.10$), pre-frail ($0.10 < eFI \leq 0.21$), and frail ($eFI > 0.21$) (Pajewski et al. 2019).

Conceptual framework

The Behavioral Model of Health Service Use (BMHSU) suggests that contextual and individual predisposing, enabling, and need factors are the primary explanatory processes that contribute to health behaviors, such as healthcare utilization, which consequently affect downstream health outcomes (Figure 1.1) (Andersen, Davidson, and Baumeister 2013). The focus of this dissertation to provide information to influence contextual-level enabling factors, with an emphasis on informing organizational-level policy and strategies that affect healthcare access and play a role in improving health outcomes. Figure 1.1 lists how we might think of each independent and dependent variable used in this dissertation in the context of each study. The first manuscript examines emergency and inpatient healthcare utilization as the primary outcome. In this context, frailty acts as an individual-level evaluated need factor. Frailty can increase the likelihood that individuals will seek or require acute care services due to a diminished physical and functional health and increased susceptibility to illness and injuries (Andersen, Davidson, and Baumeister 2013). In the second and third manuscripts examine frailty as a health outcome, or a result how these contextual- and individual-level factors and health behaviors contribute to changes in health status. Age and sex are individual-level demographic characteristics that exist prior to illness, which can be classified as predisposing variables in all analyses. Three contextual-level independent variables are used in these analysis as follows: area disadvantage, the index of concentration at the extremes, and urban-rural status. These have been examined as both enabling and predisposing factors in the literature based on the context of the study (Babitsch, Gohl, and von Lengerke 2012). The analysis of emergency and inpatient care and the development of frailty underscores their role as predisposing factors. These variables encompass various socioeconomic and environmental factors that collectively predispose individuals in that neighborhood or geographic area to have greater healthcare needs, leading to higher utilization rates or a higher probability of the development of frailty. I chose three individual-level need factors that were modifiable, accessible in the EHR, and relevant to older adults, but that did not directly contribute to the calculation of the eFI. Exploring associations of transitions with anxiety, alcohol misuse, and smoking status provide insights into what types of interventions may be useful in preventing or delaying frailty. Anxiety disorders are prevalent among older adults and rose during the COVID-19 pandemic (Andreescu and Lee 2020; Gosselin et al. 2022). Alcohol among older adults has increased over time (Breslow et al. 2017). Although smoking rates among older adults have declined, it remains a significant cause of high morbidity and mortality, particularly with elevated rates in rural areas (Hunt et al. 2023; Parker et al. 2022).

Figure 1.1

Behavioral Model of Health Service Use



Note. The underlying schematic of this figure was adapted from Andersen et al. (2013)

Objectives

My overarching objective is to use the insights gained from this research to inform contextual level enabling factors, such as policies that involve population management and risk stratification for older adults. In the first manuscript, I analyzed the collective association of frailty and area disadvantage with emergency and inpatient healthcare utilization to determine whether these constructs were dependent and useful in identifying vulnerable older adults with functional, medical, and social needs. The second and third studies were exploratory and pave the way for more directed hypothesis-driven research aimed at strategically enhancing healthcare delivery and patient outcomes overall and across urban and rural environments. The aim of the second manuscript was to characterize patterns of frailty transitions using electronic medical record (EMR) data in a unique healthcare setting and to identify demographic characteristics and actionable individual- and area-level factors associated with these transitions. In the third manuscript, I examined whether associations between these factors varied by urban-rural residence. Differences in frailty progression between urban and rural patients might suggest that healthcare organizations should consider these differences when developing targeted interventions and risk stratification strategies.

CHAPTER 2: THE ASSOCIATION OF FRAILTY AND NEIGHBORHOOD DISADVANTAGE WITH EMERGENCY DEPARTMENT VISITS AND HOSPITALIZATIONS IN OLDER ADULTS

Preliminary Note

This manuscript was published by Springer Nature in the Journal of General Internal Medicine (Lenoir et al. 2023). It is reproduced for this dissertation with permission from Springer Nature: License Number 5776551210001 (see Appendix). Citation:

Lenoir KM, Paul R, Wright E, Palakshappa D, Pajewski NM, Hanchate A, Hughes JM, Gabbard J, Wells BJ, Dulin M, Houlihan J, Callahan KE. The Association of Frailty and Neighborhood Disadvantage with Emergency Department Visits and Hospitalizations in Older Adults. J Gen Intern Med. 2023 Nov 6. doi: 10.1007/s11606-023-08503-x. Epub ahead of print. PMID: 37932543.

Introduction

As the population aged 65 years and older grows in the United States, healthcare organizations face challenges in meeting an increased need for chronic disease management, complex care, and healthcare resource consumption (Demiris et al., 2020; Rowe et al., 2016). Older adults experience high rates of emergency department (ED) visits (Ashman et al., 2020) and 16.8% have at least one hospitalization per year (National Center for Health Statistics (US), 2021) which may be avoidable in the setting of high-quality ambulatory care or preventive services (Broek et al., 2020; K W McDermott & Jiang, 2020; SoleimanvandiAzar et al., 2020) and social support (Jiwa et al., 2002). The Behavioral Model of Health Service Use posits that contextual- and individual-level predisposing, enabling, and need factors are the primary explanatory processes that explain health behaviors, such as utilization, which consequently affect downstream health outcomes (Andersen et al., 2013). Frailty, an individual-level evaluated need factor, and neighborhood disadvantage, a contextual community-level predisposing factor for hospitalizations, are two constructs that may help to identify vulnerable subsets of older adults with unmet or future medical, functional, and social needs.

Frailty is an age-related biological process resulting in a decrease in physiologic and functional reserve, which leads to increased vulnerability and elevated risk of adverse health outcomes (Clegg et al., 2013), such as mortality, falls, and disability (Bandeen-Roche et al., 2015; Han et al., 2019; Pajewski et al., 2019; Romero-Ortuno & Kenny, 2012). Even controlling for age and multi-morbidity, frailty further risk-stratifies a population of vulnerable older adults (Bandeen-Roche et al., 2015) and has emerged as an international target for screening in healthcare (Lim et al., 2022; Muscedere et al., 2016; National Health Service England, 2017) Frailty is also associated with higher levels of healthcare utilization, inclusive of the spectrum from primary care visits to inpatient hospitalizations (Ilinca & Calciolari, 2015). Frailty can increase the likelihood that individuals will seek or require acute care services due to diminished physical and functional health and increased susceptibility to illness and injuries (Andersen et al., 2013). Importantly, when based on the theory of deficit accumulation, a measure of frailty can be operationalized using routine data captured in the electronic health record (EHR) as an electronic Frailty Index (eFI) (Pajewski et al., 2019). The validity of such an approach has now been demonstrated repeatedly across several health systems and countries (Clegg et al., 2016; Kim et al., 2022; Lim et al., 2022; Muscedere et al., 2016; National Health Service England, 2017; Pajewski et al., 2019).

Socioeconomic Status (SES), a component of Social Determinants of Health (SDoH), can also influence health-related risks, outcomes, and healthcare access (Kangovi et al., 2013; National Center for Health Statistics, 2016). Outside of proxy measures such as insurance status (i.e., self-pay or qualifying for Medicaid), SES is not ascertained as part of routine medical care.

This has led to considerable interest in geographic, area-based measures such as the Area Deprivation Index (ADI), an indicator of area disadvantage. The ADI is a composite measure of 17 variables across SES domains of income, education, employment, and housing derived from U.S. Census Bureau data (Kind et al., 2014; Kind & Buckingham, 2018). Living in an area of higher disadvantage, or lower SES, is associated with an increased risk of mortality (Wong et al., 2020) and morbidity (Arcaya et al., 2016; Billings et al., 2016; Boylan & Robert, 2017; Lantos et al., 2018), in addition to higher rates of healthcare consumption (Chen et al., 2020; Hu et al., 2018; K W McDermott & Jiang, 2020; Kind et al., 2014; Spatz et al., 2020). Area disadvantage encompasses various socioeconomic and environmental factors that collectively predispose individuals living in that neighborhood to have more healthcare needs, contributing to higher utilization rates (Andersen et al., 2013). The ADI is publicly available and has the potential to facilitate screening to identify older adults who may lack social or community-based resources.

Frailty is associated with lower SES levels among older adults (Guessous et al., 2014; Lee et al., 2018; Romero-Ortuno, 2014; Wang & Hulme, 2021). SES has been examined as a moderator of frailty's effect on mortality (Gu et al., 2016; Yang & Pang, 2016), but most studies have examined the independent contribution of each factor to utilization (H.-Y. Chang et al., 2021; Ferri-Guerra et al., 2020; Han et al., 2019; Hu et al., 2018; Kind et al., 2014; Kojima, 2016; Pajewski et al., 2019; Theou et al., 2018), leaving a gap in the exploration of the intersection of frailty and socially vulnerable populations (Kurnat-Thoma et al., 2022). In addition, the myriad measures of frailty (Bandeen-Roche et al., 2020) and SES (Venzon et al., 2019) further complicate our ability to translate findings into meaningful clinical action. While several studies have shown a positive association between frailty and neighborhood disadvantage with acute healthcare utilization (Chang et al., 2021; Ferri-Guerra et al., 2020; Han et al., 2019;

Hu et al., 2018; Kind et al., 2014; Kojima, 2016; Pajewski et al., 2019; Theou et al., 2018), these studies have largely focused on re-admissions and cohorts with specific chronic diseases. Our goal was to examine the association between frailty and neighborhood disadvantage collectively, ascertained pragmatically from the EHR, with recurrent acute healthcare utilization in a primary care population of older adults. The goal is that this data may help identify vulnerable subsets of older adults with unmet or future medical, functional, and social needs who may be amenable to population health management initiatives (Andersen et al., 2013; K W McDermott & Jiang, 2020; Rowe et al., 2016).

Methods

Setting and Population

This retrospective observational cohort study included patients identified using Atrium Health Wake Forest Baptist's (AHWFB) electronic health record (EHR) (Epic, Verona, WI), who were aged 65 years and older and lived in North Carolina or lower Virginia as of January 1, 2019 (index date), and who were attributed to an affiliated Accountable Care Organization (ACO) registry. AHWFB provides primary, specialty, and hospital-based care across a 24-county region in western North Carolina. We required the presence of at least 2 ambulatory visits with blood pressure measurements taken in the 2 years preceding the index date to focus on older adults receiving some level of outpatient or primary care from AHWFB. We excluded individuals for whom we could not calculate the eFI or obtain an ADI value based on their residence. The study was approved by the Wake Forest University School of Medicine Institutional Review Board.

Key Variables

The composition and calculation of the eFI has been previously described and is currently calculated weekly for all patients aged 55 years and older at AHWFB (Pajewski et al., 2019). Frailty status was categorized as fit (eFI $\leq$ 0.10), pre-frail (0.10 < eFI $\leq$ 0.21), and frail (eFI > 0.21). For our cohort, we obtained block-level geographical identifiers (GEOID) from structured address data in the EHR as of the index date, which we linked to ADI data from 2018 (Kind et al., 2014). We used national ADI percentiles, which range from 1 to 100, with 100 representing the highest level of neighborhood disadvantage. Consistent with previous analyses of readmission risk (Hu et al., 2018; Kind et al., 2014) and guided by visual observation of unadjusted rates of utilization across ADI quantiles (Figure 2.1), we categorized neighborhood disadvantage into three groups: low deprivation (AHWFB's bottom 50th percentile; ADI percentiles 3-63), mid-deprivation (AHWFB's middle 35th percentile; ADI percentiles 64-82), and high deprivation (AHWFB's top 15th percentile; ADI percentiles 83-100). We used structured data from AHWFB's EHR and data from an admission, discharge, and transfer network (Bamboo Health), which aggregates utilization data across healthcare organizations participating in affiliated ACOs. We defined acute healthcare utilization as recurrent all-cause events, encompassing ED visits, observation stays, and inpatient hospitalizations. Each individual could experience multiple events on different days of follow-up, with events occurring on consecutive days treated as a single event. For instance, a hospitalization that followed an ED visit the next day was considered a single event, and the day of the ED visit was used as the time of the event.

We examined ED visits, observation stays, and inpatient visits over one year of follow-up. We chose this shorter length of follow-up to circumvent potential bias introduced by the

COVID-19 pandemic, which altered regular clinical activities in early 2020. Mortality information was supplemented by deterministic linkage (based on name, age, gender, date of birth, and race/ethnicity) to the North Carolina State Center for Health Statistics death index.

Statistical Analysis

To model the statistical interaction between frailty status and neighborhood disadvantage, we used a multivariate recurrent time-to-event model within a Cox proportional hazards framework, including random effects to account for within-individual correlations (Amorim & Cai, 2015). Observations were right-censored at the time of death or at the end of a 365-day follow-up window. Covariates were chosen based on theoretical and empirical association with outcomes from previous studies (Pajewski et al., 2019) and availability within the EHR. Demographic variables included sex (male, female), race and ethnicity (White, Black, Hispanic or Latinx, other), and age (years). Number of outpatient encounters ($\leq$1, 2 to 4, $\geq$5), and number of ED visits, observation stays, and inpatient encounters (0, 1, or $\geq$2) in the year prior to index date were included to account for informed presence bias (Goldstein et al., 2016) and were categorized according to each variable's distribution. Multi-morbidity was not included as a specific covariate because it is included in the eFI and thus is at least partially collinear (Callahan et al., 2021). We added a two-way interaction term to evaluate whether the relative associations of frailty status and area disadvantage with utilization were dependent. We present associations (hazard ratios) of groups with varying combinations of eFI and ADI levels relative to a reference group of older adults who were fit and living in an area of low deprivation. To quantify statistical interactions, we report the relative excess risk index (RERI) for additive effects and the multiplicative interaction (INT_M) ratios for pre-frailty and frailty by mid and high deprivation and vice versa (Knol & VanderWeele, 2012; Li & Chambless, 2007). A P-value of <0.05 was considered statistically significant. Analyses were performed in R (Version 4.2.2) (R Core Team, 2022).

Results

Of 53,791 patients attributed to affiliated ACOs that met the inclusion criteria, 49,366 (91.8%) were geocoded and linked to an ADI percentile, and 51,327 (95.4%) had an eFI. A total of 47,566 individuals had both eFI and ADI values and were able to be included in our analysis. Visual analysis indicated the distribution of our population skewed towards higher disadvantage relative to national ADI percentiles (Figure 2.2). Those categorized as frail were more likely to be female, older, and with higher comorbidity scores in addition to higher utilization of acute and outpatient care in the prior year (Table 2.1). Those with frailty were more likely to live in areas of higher deprivation relative to those categorized as pre-frail or fit.

Those living in areas of high deprivation had the highest mean cumulative event count over time within eFI categories (Figure 2.3). Unadjusted analyses indicated a higher hazard of acute care utilization for pre-frail and frail individuals relative to those who were fit (Table 2.2). Similarly, those who lived in areas of mid- and high deprivation experienced a higher hazard of acute healthcare utilization compared to those who lived in areas of low deprivation.

In an adjusted model, we observed a statistically significant interaction between frailty and disadvantage (P=0.023), indicating dependent associations holding all other covariates constant. The hazard of acute healthcare utilization increased across ascending levels of eFI and ADI and was highest for those who were frail and living in high deprivation areas (Figure 2.4). Frailty was associated with utilization across all categories of deprivation as was deprivation across eFI categories (Table 2.3). The magnitude of associations for frailty and pre-frailty with utilization were notably larger than the associations for living in areas of mid- to high deprivation. Although we did not observe multiplicative effects across levels of frailty and neighborhood disadvantage (indicating the combined effects were not greater than the product of individual effects), we observed additive effects for frailty and mid- to high deprivation categories. The estimated joint effect of frailty and high deprivation were greater than the sum of the estimated individual effects of these variables. The interaction accounted for an additional 14.9% of the total association with utilization beyond the percent of effects attributed by frailty (56.2%) and high deprivation (28.9%) alone. Similarly, the estimated joint effects of pre-frailty and mid-deprivation were greater than the sum of the individual effects. Upon further exploration, we discovered that the effects of frailty relative to the pre-frailty group were greater for those living in mid- (INT_M= 1.06, 95% CI 1.04-1.08; *P*=0.003) and high (INT_M =1.08, 95% CI >1.00-1.17; *P*=0.046) deprivation areas compared the effects within the low deprivation area.

Discussion

Our findings indicated that high-cost, high-burden acute healthcare utilization was strongly associated with pragmatic measures of frailty and neighborhood disadvantage. While these measures can be readily available from the EHR, they are not, to date, typically used as part of resource planning and risk stratification in the United States. The associations between frailty, area deprivation, and utilization are consistent with the extant literature (Chen et al., 2020; Ferri-Guerra et al., 2020; Hu et al., 2018; Ilinca & Calciolari, 2015; K W McDermott & Jiang, 2020) and suggest value in integrating these passive digital markers of risk into healthcare organizations' data infrastructure to use in scalable risk-stratification practices to identify vulnerable older adults and inform population health management efforts. A notable finding was the substantial magnitude of the correlation between frailty and utilization across all levels of neighborhood disadvantage, in accordance with trends reported for readmission rates (Han et al., 2019). We also observed that a larger proportion of older adults with frailty living in areas of mid- and high-deprivation relative to fit and pre-frail groups consistent with our knowledge that adverse SDoH conditions contribute to the deterioration of physical health and the development of frailty (Andersen et al., 2013; Ferraro, 2018; Tan et al., 2022). It may, therefore, be prudent to emphasize preventive interventions targeting social needs and functional limitations not only for the highest-risk strata but also for older adults with pre-frailty and living in areas of higher deprivation to reduce current and future high-burden events through preventing or slowing individuals' progression to frailty.

At the policy level, eFIs have gained traction in the United States (Cheng et al., 2022; Lim et al., 2022; Pajewski et al., 2019) but are not mandated as a tool for identifying vulnerable older adults in healthcare settings as is done within the United Kingdom (National Health Service England, 2017). We have also recognized the need for incorporating and addressing social needs in the healthcare sector (Kreuter et al., 2021; Venzon et al., 2019) through leveraging the widespread adoption of the EHR as outlined by the Centers for Medicare and Medicaid (Centers for Medicare and Medicaid, 2022). Healthcare organizations engaging in population health management may efficiently incorporate these scalable measures of vulnerability in automated, EHR-based risk-stratification mechanisms to quickly identify older adults with potential unmet medical, functional, and/or social needs and intervene accordingly. In a systematic review, Preston et al. (2018) found that organization-level changes that initiated practices of identifying frail and high-risk older adults (risk-stratification) and/or providing specific care management interventions could reduce ED visits, reduce inpatient admissions, and improve discharge outcomes. Tools and strategies for addressing frailty (support services, therapy services, rehabilitation, etc.), however, may differ according to the resources available in various environments. For example, those living in areas of deprivation may not reside in a safe, walkable neighborhood, have community-based exercise opportunities, or even have reliable transportation or geographic proximity to physical therapy services to participate in interventions incorporating physical activity. Care management programs, patient navigators, and community health workers are interventions that can fill social gaps, extend health services, and reduce barriers to primary and preventive care to reduce disparities and high-burden utilization (Ahmed et al., 2022; Balaban et al., 2015; Carter et al., 2018; Freeman & Rodriguez, 2011; Natale-Pereira et al., 2011; Schaaf et al., 2020). Providing these supports can increase the potential for addressing health-related issues before they become more critical, thereby reducing the necessity for acute healthcare utilization. Additionally, creating opportunities for accessible healthcare and social services offers alternative avenues for care beyond what individuals might perceive as their only option, potentially curbing unnecessary ED visits. Healthcare organizations may use risk-stratification based on the eFI and ADI to more efficiently direct these types of interventions or even partner with high-risk communities to expand resources.

This study has several strengths. First, we were able to calculate an eFI and link an ADI percentile to nearly 90% of ACO attributed patients in our health system, which demonstrates that these tools are accessible, easily applied, and therefore scalable within a healthcare organization. Second, we used multiple data sources (EHR, Bamboo Health, and vital statistics) to create a better picture of our cohort's health and utilization to compensate for the United States' fragmented data environment across competitive healthcare systems. Lastly, we used a publicly available, objective measure of neighborhood disadvantage, which aggregates multiple attributes of the context in which a person lives. Although the ecological fallacy cautions us in ascribing community-level characteristics to individuals, area-level variables capture an objective risk unattainable through subjective patient inquiry and can serve as a preliminary screening mechanism to identify patients who might benefit from a more thorough investigation of social needs. Individual area-level data may also help healthcare organizations identify communities that would most benefit from partnerships or resource distribution.

Our study has a few limitations. First, generalizability may be limited, as this study includes ACO-attributed patients within a single healthcare system. Future research should examine trends across different populations and institutional settings, especially those with clinical contact patterns where patients are not embedded in a primary care network of a given healthcare system. Second, as with most EHR studies, there is potential for incomplete ascertainment of utilization and vital status, which may inflate estimates of follow-up time free from acute healthcare utilization. This may be why our observed all-cause mortality rates for those with frailty are slightly lower than rates reported for other United States-based cohorts after one year of follow-up (Crow et al., 2018; Lohman et al., 2020). We also considered the impact of historical tracking of ACO enrollment in the EHR and disenrollment at end-of-life, which introduces potential selection bias for presumably healthier individuals remaining in ACO plans. Our acute healthcare utilization rates are in line with what we would expect given national rates for older adults (Ashman et al., 2020; National Center for Health Statistics (US), 2021) and considering a lack of comparable study populations and outcomes as well as the substantial heterogeneity in reported effect sizes for the relative associations between frailty and hospitalizations (Chang et al., 2018). Lastly, we did not account for the possibility of the time-dependent nature of the area disadvantage and frailty. However, we would not anticipate a sizeable number of individuals would experience frailty progression or relocate to an area with a substantially different level of disadvantage within the span of a year.

Future research should test whether linking the eFI and ADI to specific interventions will reduce high cost and high-burden utilization. AHWFB is currently piloting an intervention (eFRIEND, NCT05293730 clinicaltrials.gov) in which community health workers connect older adults with frailty to resources that address the functional and social needs of each patient. This pragmatic pilot trial will assess the effects of the intervention on the number of ED visits and inpatient hospitalization as a primary outcome measure.

Conclusion

Frailty and neighborhood disadvantage, measured pragmatically using the eFI and ADI, are accessible measures of risk derived from routine data collected in EHRs that may assist healthcare organizations in more effectively risk-stratifying vulnerable older adults and implementing population health management strategies. Policy and targeted interventions have the potential to reduce costly and burdensome emergency and inpatient healthcare utilization by addressing patients' unmet medical, functional, and social needs.

References

Adler, N. E., & Stead, W. W. (2015). Patients in context—EHR capture of social and behavioral determinants of health. *New England Journal of Medicine*, *372*(8), 698–701. https://doi.org/10.1056/NEJMp1413945

Ahmed, S., Chase, L. E., Wagnild, J., Akhter, N., Sturridge, S., Clarke, A., Chowdhary, P., Mukami, D., Kasim, A., & Hampshire, K. (2022). Community health workers and health equity in low- and middle-income countries: Systematic review and recommendations for policy and practice. *International Journal for Equity in Health*, *21*(1), 49. https://doi.org/10.1186/s12939-021-01615-y

Amorim, L. D., & Cai, J. (2015). Modelling recurrent events: A tutorial for analysis in epidemiology. *International Journal of Epidemiology*, *44*(1), 324–333. https://doi.org/10.1093/ije/dyu222

Andersen, R. M., Davidson, P. L., & Baumeister, S. E. (2013). Improving access to care in America: Individual and contextual indicators. In G. F. Kominski (Ed.), *Changing the U.S. health care system: Key issues in health services policy and management* (4th ed., pp. 33–69). Jossey-Bass.

Arcaya, M. C., Tucker-Seeley, R. D., Kim, R., Schnake-Mahl, A., So, M., & Subramanian, S. V. (2016). Research on neighborhood effects on health in the United States: A systematic review of study characteristics. *Social Science & Medicine*, *168*, 16–29. https://doi.org/10.1016/j.socscimed.2016.08.047

Ashman, J. J., Schappert, S. M., & Santo, L. (2020). *Emergency department visits among adults aged 60 and over: United States, 2014–2017* (367; NCHS Data Brief, pp. 1–8). National Center for Health Statistics. https://www.cdc.gov/nchs/data/databriefs/db367-h.pdf

Balaban, R. B., Galbraith, A. A., Burns, M. E., Vialle-Valentin, C. E., Larochelle, M. R., & Ross-Degnan, D. (2015). A patient navigator intervention to reduce hospital readmissions among high-risk safety-net patients: A randomized controlled trial. *Journal of General Internal Medicine*, *30*(7), 907–915. https://doi.org/10.1007/s11606-015-3185-x

Bandeen-Roche, K., Gross, A. L., Varadhan, R., Buta, B., Carlson, M. C., Huisingh-Scheetz, M., Mcadams-Demarco, M., Piggott, D. A., Brown, T. T., Hasan, R. K., Kalyani, R. R., Seplaki, C. L., Walston, J. D., & Xue, Q.-L. (2020). Principles and Issues for Physical Frailty Measurement and Its Clinical Application. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *75*(6), 1107–1112. https://doi.org/10.1093/gerona/glz158

Bandeen-Roche, K., Seplaki, C. L., Huang, J., Buta, B., Kalyani, R. R., Varadhan, R., Xue, Q.-L., Walston, J. D., & Kasper, J. D. (2015). Frailty in older adults: A nationally representative profile in the United States. *The Journals of Gerontology: Series A*, *70*(11), 1427–1434. https://doi.org/10.1093/gerona/glv133

Billings, M. E., Johnson, D. A., Simonelli, G., Moore, K., Patel, S. R., Diez Roux, A. V., & Redline, S. (2016). Neighborhood walking environment and activity level are associated with OSA. *Chest*, *150*(5), 1042–1049. https://doi.org/10.1016/j.chest.2016.06.012

Boylan, J. M., & Robert, S. A. (2017). Neighborhood SES is particularly important to the cardiovascular health of low SES individuals. *Social Science & Medicine*, *188*, 60–68. https://doi.org/10.1016/j.socscimed.2017.07.005

Broek, S. van den, Heiwegen, N., Verhofstad, M., Akkermans, R., Westerop, L. van, Schoon, Y., & Hesselink, G. (2020). Preventable emergency admissions of older adults: An observational mixed-method study of rates, associative factors and underlying causes in two Dutch hospitals. *BMJ Open*, *10*(11), e040431. https://doi.org/10.1136/bmjopen-2020-040431

Callahan, K. E., Clark, C. J., Edwards, A. F., Harwood, T. N., Williamson, J. D., Moses, A. W., Willard, J. J., Cristiano, J. A., Meadows, K., Hurie, J., High, K. P., Meredith, J. W., & Pajewski, N. M. (2021). Automated frailty screening at-scale for pre-operative risk stratification using the electronic frailty index. *Journal of the American Geriatrics Society*, *69*(5), 1357–1362. https://doi.org/10.1111/jgs.17027

Carter, N., Valaitis, R. K., Lam, A., Feather, J., Nicholl, J., & Cleghorn, L. (2018). Navigation delivery models and roles of navigators in primary care: A scoping literature review. *BMC Health Services Research*, *18*, 1–13. https://doi.org/10.1186/s12913-018-2889-0

Centers for Medicare and Medicaid. (2022). *CMS framework for health equity 2022–2032* (pp. 1–30). Department of Health and Human Services. https://www.cms.gov/files/document/cms-framework-health-equity-2022.pdf

Chang, H.-Y., Hatef, E., Ma, X., Weiner, J. P., & Kharrazi, H. (2021). Impact of area deprivation index on the performance of claims-based risk-adjustment models in predicting health care costs and utilization. *Population Health Management*, *24*(3), 403–411. https://doi.org/10.1089/pop.2020.0135

Chang, S.-F., Lin, H.-C., & Cheng, C.-L. (2018). The Relationship of Frailty and Hospitalization Among Older People: Evidence from a Meta-Analysis. *Journal of Nursing Scholarship: An Official Publication of Sigma Theta Tau International Honor Society of Nursing*, *50*(4), 383–391. https://doi.org/10.1111/jnu.12397

Chen, C., Weider, K., Konopka, K., & Danis, M. (2014). Incorporation of socio-economic status indicators into policies for the meaningful use of electronic health records. *Journal of*

Health Care for the Poor and Underserved, *25*(1), 1–16. https://doi.org/10.1353/hpu.2014.0040

Chen, M., Tan, X., & Padman, R. (2020). Social determinants of health in electronic health records and their impact on analysis and risk prediction: A systematic review. *Journal of the American Medical Informatics Association*, *27*(11), 1764–1773. https://doi.org/10.1093/jamia/ocaa143

Cheng, D., Dumontier, C., Sheikh, A. R., La, J., Brophy, M. T., Do, N. V., Driver, J. A., Tuck, D. P., & Fillmore, N. R. (2022). Prognostic value of the veterans affairs frailty index in older patients with non-small cell lung cancer. *Cancer Medicine*, *11*(15), 3009–3022. https://doi.org/10.1002/cam4.4658

Clegg, A., Bates, C., Young, J., Ryan, R., Nichols, L., Ann Teale, E., Mohammed, M. A., Parry, J., & Marshall, T. (2016). Development and validation of an electronic frailty index using routine primary care electronic health record data. *Age and Ageing*, *45*(3), 353–360. https://doi.org/10.1093/ageing/afw039

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. *Lancet*, *381*(9868), 752–762. https://doi.org/10.1016/S0140-6736(12)62167-9

Crow, R. S., Lohman, M. C., Titus, A. J., Bruce, M. L., Mackenzie, T. A., Bartels, S. J., & Batsis, J. A. (2018). Mortality Risk Along the Frailty Spectrum: Data from the National Health and Nutrition Examination Survey 1999 to 2004. *Journal of the American Geriatrics Society*, *66*(3), 496–502. https://doi.org/10.1111/jgs.15220

Demiris, G., Hodgson, N. A., Sefcik, J. S., Travers, J. L., McPhillips, M. V., & Naylor, M. D. (2020). High value care for older adults with complex care needs: Leveraging nurses as innovators. *Nursing Outlook*, *68*(1), 26–32. https://doi.org/10.1016/j.outlook.2019.06.019

Ferraro, K. F. (2018). Accumulation processes. In *The gerontological imagination: An integrative paradigm of aging* (pp. 90–112). Oxford University Press. 10.1093/med/9780190665340.001.0001

Ferri-Guerra, J., Aparicio-Ugarriza, R., Salguero, D., Baskaran, D., Mohammed, Y. N., Florez, H., & Ruiz, J. G. (2020). The association of frailty with hospitalizations and mortality among community dwelling older adults with diabetes. *The Journal of Frailty & Aging*, *9*(2), 94–100. https://doi.org/10.14283/jfa.2019.31

Freeman, H. P., & Rodriguez, R. L. (2011). The history and principles of patient navigation. *Cancer*, *117*(15 Suppl), 3539–3542. https://doi.org/10.1002/cncr.26262

Goldstein, B. A., Bhavsar, N. A., Phelan, M., & Pencina, M. J. (2016). Controlling for informed presence bias due to the number of health encounters in an electronic health record. *American Journal of Epidemiology*, *184*(11), 847–855. https://doi.org/10.1093/aje/kww112

Gu, D., Yang, F., & Sautter, J. (2016). Socioeconomic status as a moderator between frailty and mortality at old ages. *BMC Geriatrics*, *16*(1), 151. https://doi.org/10.1186/s12877-016-0322-2

Guessous, I., Luthi, J.-C., Bowling, C. B., Theler, J.-M., Paccaud, F., Gaspoz, J.-M., & McClellan, W. (2014). Prevalence of frailty indicators and association with socioeconomic status in middle-aged and older adults in a Swiss region with universal health insurance coverage: A population-based cross-sectional study. *Journal of Aging Research*, *2014*, 1–8. https://doi.org/10.1155/2014/198603

Han, L., Clegg, A., Doran, T., & Fraser, L. (2019). The impact of frailty on healthcare resource use: A longitudinal analysis using the Clinical Practice Research Datalink in England. *Age and Ageing*, *48*(5), 665–671. https://doi.org/10.1093/ageing/afz088

Hu, J., Kind, A. J. H., & Nerenz, D. (2018). Area deprivation index predicts readmission risk at an urban teaching hospital. *American Journal of Medical Quality*, *33*(5), 493–501. https://doi.org/10.1177/1062860617753063

Ilinca, S., & Calciolari, S. (2015). The patterns of health care utilization by elderly Europeans: Frailty and its implications for health systems. *Health Services Research*, *50*(1), 305–320. https://doi.org/10.1111/1475-6773.12211

Jiwa, M., Gerrish, K., Gibson, A., & Scott, H. (2002). Preventing avoidable hospital admission of older people. *British Journal of Community Nursing*, *7*(8), 426–431. https://doi.org/10.12968/bjcn.2002.7.8.10650

K W McDermott, & Jiang, H. J. (2020). *Characteristics and costs of potentially preventable inpatient stays, 2017* (259; HCUP Statistical Brief). Agency for Healthcare Research and Quality. https://hcup-us.ahrq.gov/reports/statbriefs/sb259-Potentially-Preventable-Hospitalizations-2017.jsp

Kangovi, S., Barg, F. K., Carter, T., Long, J. A., Shannon, R., & Grande, D. (2013). Understanding why patients of low socioeconomic status prefer hospitals over ambulatory care. *Health Affairs (Project Hope)*, *32*(7), 1196–1203. https://doi.org/10.1377/hlthaff.2012.0825

Kim, D. J., Massa, M. S., Potter, C. M., Clarke, R., & Bennett, D. A. (2022). Systematic review of the utility of the frailty index and frailty phenotype to predict all-cause mortality in older people. *Systematic Reviews*, *11*, 187. https://doi.org/10.1186/s13643-022-02052-w

Kind, A. J. H., & Buckingham, W. R. (2018). Making neighborhood-disadvantage metrics accessible—The neighborhood atlas. *New England Journal of Medicine*, *378*(26), 2456–2458. https://doi.org/10.1056/NEJMp1802313

Kind, A. J. H., Jencks, S., Brock, J., Yu, M., Bartels, C., Ehlenbach, W., Greenberg, C., & Smith, M. (2014). Neighborhood socioeconomic disadvantage and 30 day rehospitalizations: An analysis of Medicare data. *Annals of Internal Medicine*, *161*(11), 765–774. https://doi.org/10.7326/M13-2946

Knol, M. J., & VanderWeele, T. J. (2012). Recommendations for presenting analyses of effect modification and interaction. *International Journal of Epidemiology*, *41*(2), 514–520. https://doi.org/10.1093/ije/dyr218

Kojima, G. (2016). Frailty as a predictor of hospitalisation among community-dwelling older people: A systematic review and meta-analysis. *J Epidemiol Community Health*, *70*(7), 722–729. https://doi.org/10.1136/jech-2015-206978

Kreuter, M. W., Thompson, T., McQueen, A., & Garg, R. (2021). Addressing social needs in health care settings: Evidence, challenges, and opportunities for public health. *Annual Review of Public Health*, *42*(1), 329–344. https://doi.org/10.1146/annurev-publhealth-090419-102204

Kurnat-Thoma, E. L., Murray, M. T., & Juneau, P. (2022). Frailty and Determinants of Health among Older Adults in the United States 2011–2016. *Journal of Aging and Health*, *34*(2), 233–244. https://doi.org/10.1177/08982643211040706

Lantos, P. M., Hoffman, K., Permar, S. R., Jackson, P., Hughes, B. L., Kind, A., & Swamy, G. (2018). Neighborhood disadvantage is associated with high cytomegalovirus seroprevalence in pregnancy. *Journal of Racial and Ethnic Health Disparities*, *5*(4), 782–786. https://doi.org/10.1007/s40615-017-0423-4

Lee, D. R., Santo, E. C., Lo, J. C., Ritterman Weintraub, M. L., Patton, M., & Gordon, N. P. (2018). Understanding functional and social risk characteristics of frail older adults: A cross-sectional survey study. *BMC Family Practice*, *19*(1), 1–12. https://doi.org/10.1186/s12875-018-0851-1

Li, R., & Chambless, L. (2007). Test for additive interaction in proportional hazards models. *Annals of Epidemiology*, *17*(3), 227–236. https://doi.org/10.1016/j.annepidem.2006.10.009

Lim, A., Choi, J., Ji, H., & Lee, H. (2022). Frailty assessment using routine clinical data: An integrative review. *Archives of Gerontology and Geriatrics*, *99*, 104612. https://doi.org/10.1016/j.archger.2021.104612

Lohman, M. C., Sonnega, A. J., Resciniti, N. V., & Leggett, A. N. (2020). Frailty Phenotype and Cause-Specific Mortality in the United States. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *75*(10), 1935–1942. https://doi.org/10.1093/gerona/glaa025

Moscrop, A., & MacPherson, P. (2014). Should doctors record their patients' income? *The British Journal of General Practice*, *64*(627), e672–e674. https://doi.org/10.3399/bjgp14X682009

Muscedere, J., Andrew, M. K., Bagshaw, S. M., Estabrooks, C., Hogan, D., Holroyd-Leduc, J., Howlett, S., Lahey, W., Maxwell, C., McNally, M., Moorhouse, P., Rockwood, K., Rolfson, D., Sinha, S., Tholl, B., & Canadian Frailty Network (CFN). (2016). Screening for frailty in Canada's health care system: A time for action. *Canadian Journal on Aging*, *35*(3), 281–297. https://doi.org/10.1017/S0714980816000301

Natale-Pereira, A., Enard, K. R., Nevarez, L., & Jones, L. A. (2011). The role of patient navigators in eliminating health disparities. *Cancer*, *117*(15 Suppl), 3541–3550. https://doi.org/10.1002/cncr.26264

National Center for Health Statistics. (2016). *Chapter 39: Social determinants of health. Healthy People 2020 midcourse review*. National Center for Health Statistics. https://www.cdc.gov/nchs/data/hpdata2020/HP2020MCR-C39-SDOH.pdf

National Center for Health Statistics (US). (2021). *Table 40, Persons with hospital stays in the past year, by selected characteristics: United States, selected years 1997–2018* [Text]. National Center for Health Statistics (US). https://www.ncbi.nlm.nih.gov/books/NBK569311/table/ch3.tab40/

National Health Service England. (2017). *NHS England » Identifying frailty*. Supporting Routine Frailty Identification and Frailty through the GP Contract 2017/2018. https://www.england.nhs.uk/ourwork/ltc-op-eolc/older-people/frailty/supporting-resources-general-practice/

Pajewski, N. M., Lenoir, K., Wells, B. J., Williamson, J. D., & Callahan, K. E. (2019). Frailty screening using the electronic health record within a Medicare accountable care organization. *Journals of Gerontology*, *74*(11), 1771–1777. https://doi.org/10.1093/gerona/glz017

Preston, L., Chambers, D., Campbell, F., Cantrell, A., Turner, J., & Goyder, E. (2018). What evidence is there for the identification and management of frail older people in the emergency department? A systematic mapping review. *Health Services and Delivery Research*, *6*(16), 1–168. https://doi.org/10.3310/hsdr06160

R Core Team. (2022). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Romero-Ortuno, R. (2014). The Frailty Index in Europeans: Association with determinants of health. *Geriatrics & Gerontology International*, *14*(2), 420–429. https://doi.org/10.1111/ggi.12122

Romero-Ortuno, R., & Kenny, R. A. (2012). The frailty index in Europeans: Association with age and mortality. *Age and Ageing*, *41*(5), 684–689. https://doi.org/10.1093/ageing/afs051

Rowe, J. W., Fulmer, T., & Fried, L. (2016). Preparing for better health and health care for an aging population. *JAMA*, *316*(16), 1643–1644. https://doi.org/10.1001/jama.2016.12335

Schaaf, M., Warthin, C., Freedman, L., & Topp, S. M. (2020). The community health worker as service extender, cultural broker and social change agent: A critical interpretive synthesis of roles, intent and accountability. *BMJ Global Health*, *5*(6), e002296. https://doi.org/10.1136/bmjgh-2020-002296

SoleimanvandiAzar, N., Mohaqeqi Kamal, S. H., Sajjadi, H., Ghaedamini Harouni, G., Karimi, S. E., Djalalinia, S., & Setareh Forouzan, A. (2020). Determinants of outpatient health service utilization according to Andersen's behavioral model: A systematic scoping review. *Iranian Journal of Medical Sciences*, *45*(6), 405–424. https://doi.org/10.30476/ijms.2020.85028.1481

Spatz, E. S., Bernheim, S. M., Horwitz, L. I., & Herrin, J. (2020). Community factors and hospital wide readmission rates: Does context matter? *PloS One*, *15*(10), 1–14. https://doi.org/10.1371/journal.pone.0240222

Tan, V., Chen, C., & Merchant, R. A. (2022). Association of social determinants of health with frailty, cognitive impairment, and self-rated health among older adults. *PLOS ONE*, *17*(11), e0277290. https://doi.org/10.1371/journal.pone.0277290

Theou, O., Sluggett, J. K., Bell, J. S., Lalic, S., Cooper, T., Robson, L., Morley, J. E., Rockwood, K., & Visvanathan, R. (2018). Frailty, hospitalization, and mortality in residential aged care. *The Journals of Gerontology: Series A*, *73*(8), 1090–1096. https://doi.org/10.1093/gerona/glx185

Venzon, A., Le, T. B., & Kim, K. (2019). Capturing social health data in electronic systems: A systematic review. *CIN: Computers, Informatics, Nursing*, *37*(2), 90. https://doi.org/10.1097/CIN.0000000000000481

Wang, J., & Hulme, C. (2021). Frailty and socioeconomic status: A systematic review. *Journal of Public Health Research*, *10*(3), 2036. https://doi.org/10.4081/jphr.2021.2036

Wong, M. S., Steers, W. N., Hoggatt, K. J., Ziaeian, B., & Washington, D. L. (2020). Relationship of neighborhood social determinants of health on racial/ethnic mortality disparities in US veterans-mediation and moderating effects. *Health Services Research*, *55*(S2), 851–862. https://doi.org/10.1111/1475-6773.13547

Yang, F., & Pang, J. S. (2016). Socioeconomic status, frailty, and subjective well-being: A moderated mediation analysis in elderly Chinese: *Journal of Health Psychology*. https://doi.org/10.1177/1359105316675211

Table 2.1: Characteristics of the analytic cohort by eFI category

	Overall	Fit	Pre-frail	Frail	p
N	47,566	11,600	25,943	10,023	
Age, years, (median [IQR])	73.4 [69.3-79.3]	71.44 [68.2-75.9]	73.6 [69.43-79.2]	76.3 [71.1-83.0]	<0.001
Age, no. (%)					<0.001
65 to <75	25,203 (53.0)	7,659 (66.0)	13,546 (52.2)	3,998 (39.9)	
75 to <85	17,460 (36.7)	3,419 (29.5)	9,884 (38.1)	4,157 (41.5)	
85+	4,903 (10.3)	522 (4.5)	2,513 (9.7)	1,868 (18.6)	
Sex, no. (%)					<0.001
Female	28,287 (59.5)	6,243 (53.8)	15,330 (59.1)	6,714 (67.0)	
Male	19,279 (40.5)	5,357 (46.2)	10,613 (40.9)	3,309 (33.0)	
Race/ethnicity, no. (%)					<0.001
Black non-Hispanic or Latinx	5,518 (11.6)	1,084 (9.3)	3,176 (12.2)	1,258 (12.6)	
Hispanic or Latinx	610 (1.3)	163 (1.4)	323 (1.2)	124 (1.2)	
Other non-Hispanic or Latinx	1,076 (2.3)	340 (2.9)	561 (2.2)	175 (1.7)	
White non-Hispanic or Latinx	40,362 (84.9)	10,013 (86.3)	21,883 (84.4)	8,466 (84.5)	
Charlson comorbidity index category, no (%)					<0.001
0 to <2	27,343 (57.5)	9,969 (85.9)	15,112 (58.3)	2,262 (22.6)	
2 to <4	13,273 (27.9)	1,472 (12.7)	8,046 (31.0)	3,755 (37.5)	
4+	6,950 (14.6)	159 (1.4)	2,785 (10.7)	4,006 (40.0)	
Area Deprivation					<0.001
Low (lowest 50%)	22,944 (48.2)	6,365 (54.9)	12,312 (47.5)	4,267 (42.6)	
Mid (mid 35%)	17,208 (36.2)	3,848 (33.2)	9,491 (36.6)	3,869 (38.6)	
High (top 15%)	7,414 (15.6)	1,387 (12.0)	4,140 (16.0)	1,887 (18.8)	
Outpatient visits in prior year, no. (%)					<0.001
0-1	19,853 (41.7)	6,267 (54.0)	10,724 (41.3)	2,862 (28.6)	
2-4	13,154 (27.7)	3,432 (29.6)	7,364 (28.4)	2,358 (23.5)	
5+	14,559 (30.6)	1,901 (16.4)	7,855 (30.3)	4,803 (47.9)	
Emergency, observation, and inpatient visits in prior year, no. (%)					<0.001
0	40,055 (84.2)	10,796 (93.1)	22,257 (85.8)	7,002 (69.9)	
1	5,005 (10.5)	654 (5.6)	2,665 (10.3)	1,686 (16.8)	
2+	2,506 (5.3)	150 (1.3)	1021 (3.9)	1,335 (13.3)	
Mortality during analytic period, no. (%)	199 (0.4)	12 (0.1)	90 (0.3)	97 (1.0)	<0.001

Note. Differences between groups were assessed using a Chi-square test for categorical variables and Kruskal Wallis for nonparametric numeric variables. Log-rank P-value reported for mortality.

Table 2.2: Unadjusted associations of eFI and area deprivation categories with utilization

Variable	Events / Rate per 100 person years	Unadjusted HR (95% CI)	*P*-value
eFI category			
Fit	2,208 / 19.1	Reference	
Pre-frail	9,688 / 37.5	1.97 (1.85-2.10)	<0.001
Frail	8,669 / 87.3	4.60 (4.30-4.92)	<0.001
Area deprivation			
Low (lowest 50%)	8,662 / 37.9	Reference	
Mid (mid 35%)	7,400 / 43.2	1.14 (1.09-1.20)	<0.001
High (top 15%)	4,503 / 61.0	1.61 (1.52-1.71)	<0.001

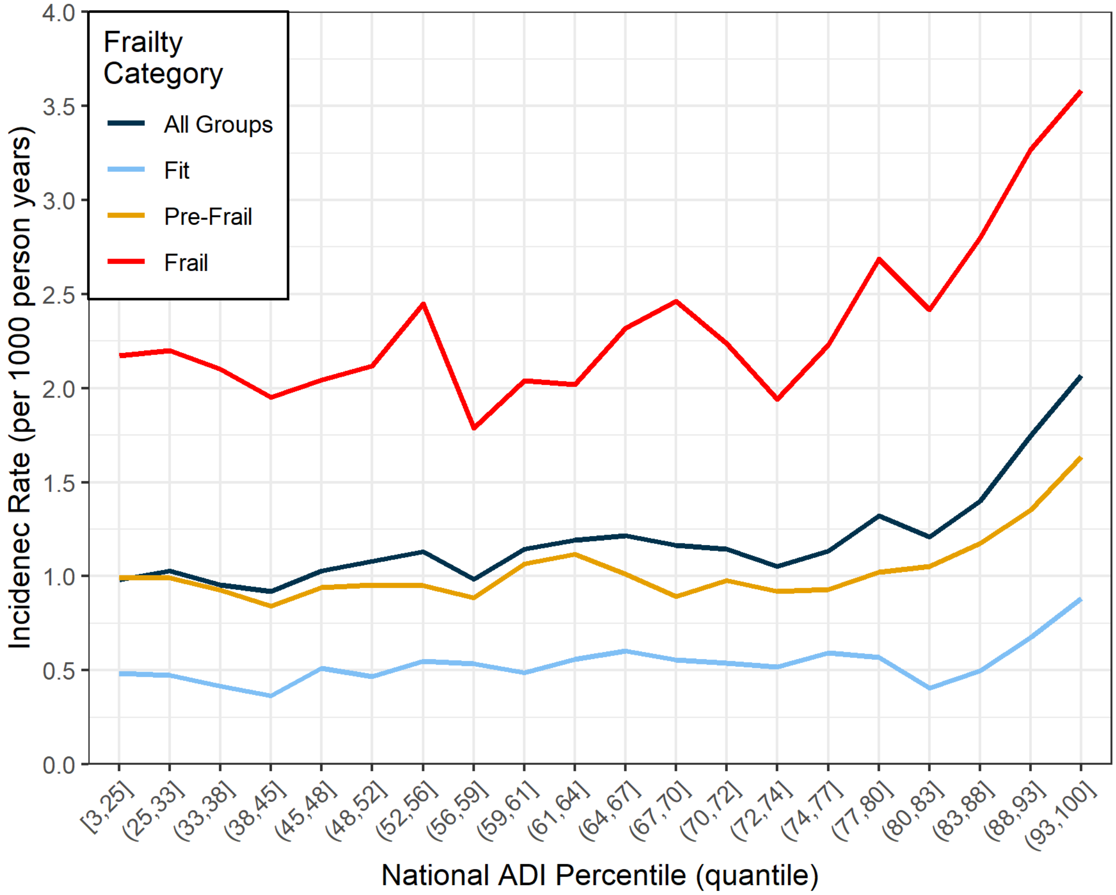
Table 2.3: Relative associations of eFI and deprivation categories with utilization including additive and multiplicative effects

	eFI contrast HR (95% CI); *P*	
Area deprivation	Pre-Frail: Fit	Frail: Fit
Low	1.54 (1.45-1.65); <0.001	2.39 (2.23-2.56); <0.001
Mid (mid 35%)	1.43 (1.32-1.55); <0.001	2.44 (2.25-2.65); <0.001
High (top 15%)	1.58 (1.41-1.78); <0.001	2.64 (2.35-2.97); <0.001
	Deprivation contrast HR (95% CI); *P*	
eFI category	Mid: Low	High: Low
Fit	1.16 (1.06-1.28); 0.001	1.22 (1.08-1.38); 0.002
Pre-frail	1.08 (1.03-1.13); 0.001	1.25 (1.19-1.32); <0.001
Frail	1.19 (1.13-1.25); <0.001	1.35 (1.28-1.43); <0.001
	Measure of interaction	
eFI and ADI category	**Additive effects (95% CI); *P***	**Multiplicative effects (95% CI); *P***
Pre-frail and Mid	-0.05 (-0.17-0.08); 0.763	0.92 (0.83-1.02); 0.135
Pre-frail and High	0.17 (<0.01-0.34); 0.028	1.02 (0.90-1.17); 0.720
Frail and Mid	0.29 (0.13-0.45); <0.001	1.02 (0.92-1.13); 0.675
Frail and High	0.62 (0.41-0.83); <0.001	1.11 (0.97-1.27); 0.142

Note. Model adjusted for age, race, gender, outpatient and acute care utilization, the interaction between frailty and deprivation, and random effects for within-subject correlation.

Figure 2.1

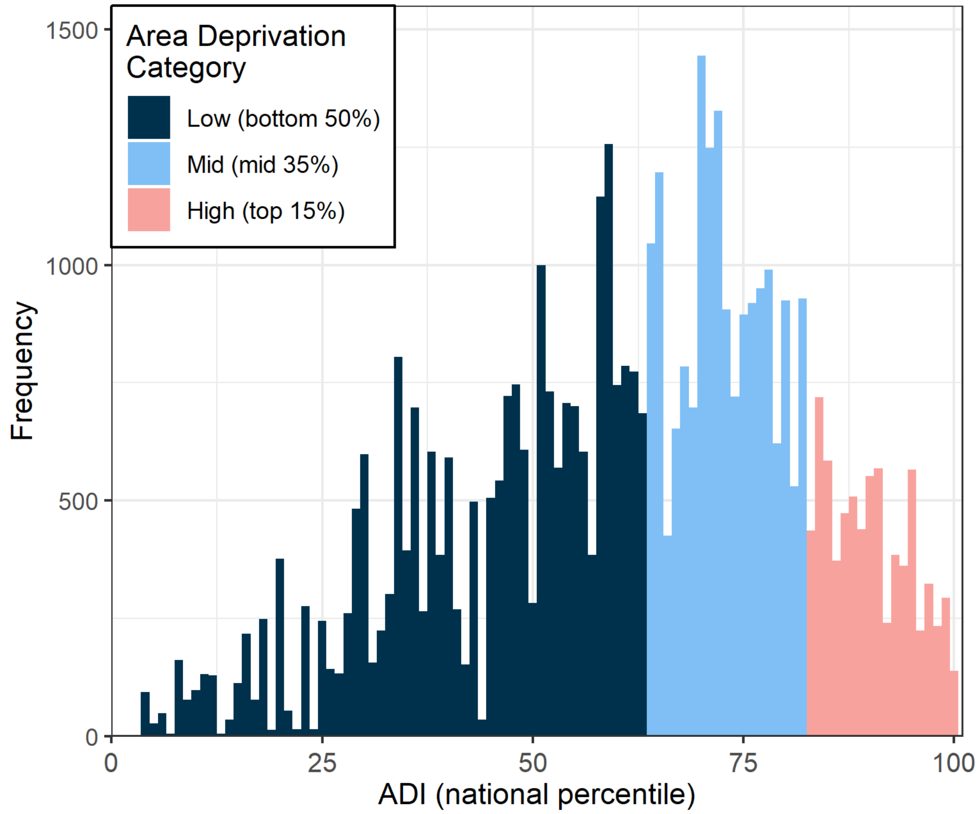
Line graph of unadjusted utilization rate across ADI quantiles



Note. National ADI values were categorized into 20 quantiles based on AHWFB's distribution of national ADI values. Parentheses and brackets are used to indicate whether an endpoint value is not included or included in the quantile, respectively.

Figure 2.2

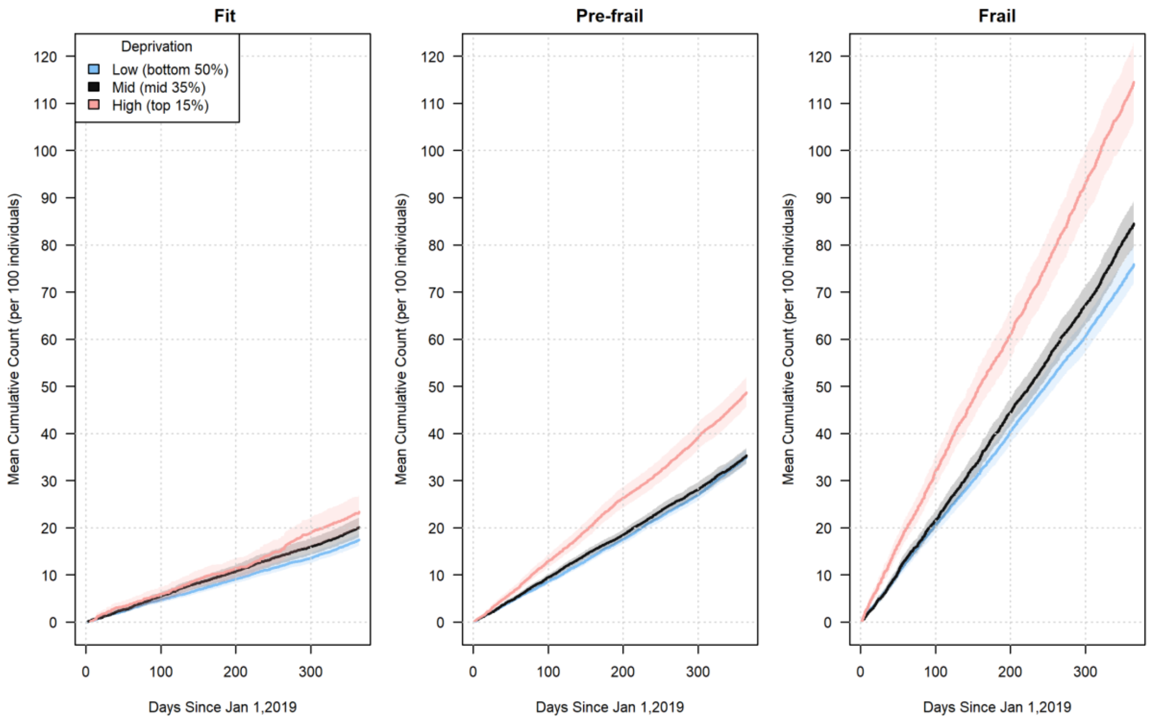
Histogram of ADI percentile at AHWFB



Note. ADI indicates area deprivation index and AHWFB indicates Atrium Health Wake Forest Baptist

Figure 2.3

Unadjusted cumulative count of utilization over time by deprivation and eFI

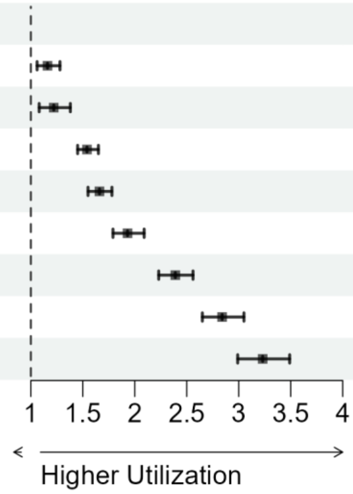


Note. 95% confidence intervals derived from bootstrapping with 1,000 samples for each stratum.

Figure 2.4

Associations of eFI and area deprivation categories with utilization

eFI	Deprivation	N	Rate/100 py	HR (95% CI)
Fit	Low	6,365	17.5	Ref
	Mid	3,848	20.1	1.16 (1.06 to 1.28)
	High	1,387	23.4	1.22 (1.08 to 1.38)
Pre-frail	Low	12,312	35.1	1.54 (1.45 to 1.65)
	Mid	9,491	35.5	1.66 (1.55 to 1.78)
	High	4,140	48.8	1.93 (1.79 to 2.09)
Frail	Low	4,267	76.5	2.39 (2.23 to 2.56)
	Mid	3,869	85.3	2.84 (2.65 to 3.05)
	High	1,887	115.7	3.23 (2.99 to 3.49)



Note. Model adjusted for age, race, gender, outpatient and acute care utilization in the prior year, the interaction between frailty and deprivation, and random effects for within-subject correlation. All p-values corresponding to Hazard Ratios (HR) are <0.001. PY indicates person-years and CI indicates 95% confidence interval.

CHAPTER 3: CHARACTERIZING FRAILTY STATE TRANSITIONS USING PRAGMATIC ELECTRONIC MEDICAL RECORD DATA: A LONGITUDINAL STUDY WITHIN A US HEALTHCARE ORGANIZATION

Introduction

Older adults are the fastest growing population not only in the United States but also on a global scale (World Health Organization 2015) and are anticipated to comprise a quarter of the population by 2060 (U.S. Census Bureau, 2023). Investigating the development of frailty, a well-established and internationally-recognized indicator of elevated risk among older adults, could help us identify potential points of intervention to prevent or delay the onset of frailty (Ofori-Asenso et al. 2019). Frailty is a clinical syndrome associated with aging that is characterized by diminished physiological reserve and a decline in multiple system functions, leading to reduced resilience to even modest stressors and increased susceptibility to adverse outcomes like mortality, morbidity, falls, and hospitalizations (Clegg et al. 2016; Lenoir et al. 2023; Pajewski et al. 2019; Vermeiren et al. 2016; Xue 2011). Frailty can be operationalized as a phenotype that integrates physical criteria (Fried et al. 2001) or quantification of deficits recorded using routinely collected data in healthcare settings (Rockwood and Mitnitski 2007), which can be implemented as an electronic Frailty Index (eFI) (Clegg et al. 2016; Pajewski et al. 2019).

A global review highlights the risk of developing frailty among individuals aged 60 years and older, with an incidence of 43.4 new cases per 1000 person-years among those who were fit, and 150.6 new cases per 1000 person-years among those with pre-frailty (Ofori-Asenso et al. 2019). In the United States, pre-frailty and frailty were estimated to affect around fifteen and forty-five percent of community-dwelling older adults in 2011, respectively (Bandeen-Roche et al. 2015). The anticipated increases in frailty prevalence are expected to both increase the burden and costs associated with healthcare (Kwak and Thompson 2020; Shi et al. 2023). Furthermore, frailty disproportionately affects women and those from racially, ethnically, and socioeconomically marginalized backgrounds (Bandeen-Roche et al. 2015; He, Goodkind, and Kowal 2016; Walsh et al. 2023), underscoring the importance of frailty prevention as a critical public health priority for equity (Cesari et al. 2016).

The development of frailty is not an inevitable consequence of aging, as individuals can sustain a robust state well into later years of life (Markle-Reid and Browne 2003). Moreover, this condition is dynamic and may be reversible where individuals can transition into and out of different frailty states (Kolle et al. 2023; Markle-Reid and Browne 2003; Travers et al. 2019). There is robust evidence that frailty is associated with a host of adverse outcomes, but we know less about who is at risk of moving into more severe states of vulnerability that may be difficult to reverse (Hoogendijk and Dent 2022; Kojima et al. 2019). Most research has examined frailty using cross-sectional measurements at a single point in time (Hoogendijk and Dent 2022). While longitudinal research examining the development of frailty is still nascent, this field has focused on trajectory patterns (Álvarez-Bustos et al. 2022; Bai et al. 2021; Chamberlain et al. 2016; Ferrante et al. 2015; Marshall et al. 2015; Welstead et al. 2021) and state transitions to understand frailty progression and improvement (Hoogendijk and Dent 2022). Trajectories refer to the long-term patterns and directions of continuous frailty measurements over time and transitions denote the movement between different frailty states over time (fit, pre-frail, and frail). While trajectory analyses provide a broader overview of frailty, research on state transitions offers valuable insights into critical transition points and the factors associated with changes between different frailty states (e.g., fit, pre-frail, and frail).

Frailty transition research is limited and has focused on cohorts embedded in healthcare systems with nationalized structures, or studies with selective participation and survey samples (Romero-Ortuno et al. 2021; Walsh et al. 2023). This study introduces a novel perspective by examining frailty transitions within the U.S. healthcare setting, a market-driven system in which numerous private organizations provide insurance and healthcare services and vie for patients (L. Shi and Singh 2021). Although most older adults (>65 years) qualify for the public provision of Medicare that covers inpatient care, individuals have a choice in opting into the degree of additional insurance to cover outpatient care and any additional needs for a monthly premium with varying out-of-pocket costs (El-Nahal 2020). Patients also have some choice as to which organizations they frequent for particular services leading to scenarios where individuals move between and receive care from multiple organizations. This study offers a pragmatic examination of how we observe frailty state transition patterns at a single healthcare organization in a context with unique operational challenges while contributing to an emerging field of longitudinal frailty research. Our objective was to characterize patterns of frailty transitions using electronic medical record (EMR) data and to identify factors associated with transitions, with a focus on progressive transitions. We examined associations with demographic characteristics and actionable individual- (anxiety, alcohol misuse, and smoking status), and area-level (deprivation and concentrated disadvantage) factors.

Methods

Setting and Population

This study was approved by the Wake Forest University School of Medicine Institutional Review Board and the University of North Carolina Institutional Review Board. This retrospective observational cohort study included adults aged 55 and older with a measurable eFI state (fit, pre-frail, or frail) on October 1, 2018, using Atrium Health Wake Forest Baptist's (AHWFB) electronic medical record (EMR) (Epic, Verona, WI). AHWFB provides primary, specialty, and hospital-based care across a 24-county region in western North Carolina with a service catchment area extending into southwest Virginia. A prerequisite for a calculable eFI is that patients were required to attend at least two outpatient visits with a corresponding measured blood pressure in the previous two years. To facilitate the inclusion of patients who would be accessible to AHWFB, we limited our study population to individuals residing in North Carolina and Virginia, who had a primary care physician affiliated with AHWFB designated in the EMR. This approach ensured we focused on patients actively engaged in care at our healthcare organization and who would be accessible for population management and intervention.

Data Structure

We calculated longitudinal eFIs at annual intervals from October 2018 through October 2022. Between these discrete time intervals, the exact timing of transitions between states was unknown while the date of death was directly observed. Given the objective of focusing on identifying risk for progression into more severe states from the perspective of who would be reachable using EMR data, we did not incorporate deaths occurring more than a year after the last observed state. Excluding deaths beyond a year maintains a consistent observational window for individuals, avoids assumptions and uncertainty regarding the individual's state before death, facilitates model parsimony, and ensures that the transitions and rates modeled are closely related to the observed states making the findings more directly interpretable.

Key Variables

An eFI has been developed and calculated weekly for patients aged 55 and older at AHWFB since 2019 (Pajewski et al. 2019). We categorized frailty states based on continuous eFI scores as follows: fit (eFI < 0.10), pre-frail ($0.10 <$ eFI ≤ 0.21), and frail (eFI > 0.21). We used structured data from AHWFB's EMR for descriptive statistics and covariates. Demographic variables included sex (male and female) and age, which was categorized based on distribution and common cut-offs (55 to 64, 65 to 74, and 75+ years). We extracted smoking status from patients' social history at encounters and coded this dichotomously as either Never or Former/Current. We identified comorbidities, anxiety, and alcohol misuse using International Classification of Diseases, Tenth Revision (ICD-10) codes from the problem list and encounters (Quan et al. 2011; Ströhle, Gensichen, and Domschke 2018; Tonelli et al. 2015). To account for variations in primary care appointments, we employed a two-year look-back period for encounter-level ICD-10 codes for each assessed time point, ensuring comprehensive data capture.

We obtained block-level geographical identifiers (GEOID) from structured address data in the EMR at the time of each eFI observation. These were linked to five-year estimate of national percentiles from the 2022 Area Deprivation Index (ADI) (Kind and Buckingham 2018) and the index of concentrations of the extremes for race (ICE_{race}) (Feldman et al. 2015; Massey 1996). The ADI, an area-level measure of socioeconomic disadvantage, was coded dichotomously into high (national ADI percentile >85) and mid/low deprivation (ADI < 85). This threshold is consistently associated with adverse events (Hu, Kind, and Nerenz 2018; Kind et al. 2014; Lenoir et al. 2023). We employed the ICE_{race} to quantify the degree of concentration of disadvantaged populations residing in a block group, using it as a proxy for structural racism (Chambers et al. 2019). We dichotomized this continuous measure into high disadvantaged concentration ($ICE_{race} < 0$) vs. mid to low disadvantaged concentration ($ICE_{race} \leq 0$) given that this measure was skewed toward higher concentrations of advantaged populations (White non-Hispanic/Latinx). Mortality data from the EMR were supplemented with vital statistics from North Carolina, which was deterministically linked to patient data by AHWFB's Clinical and Translational Science Institute.

Statistical analysis

We report observed prevalence over time and employed a multistate modeling approach using the "msm" package in R (Jackson 2011) to investigate frailty-based transitions and to identify factors associated with progression to more severe states as well as improvement (Le-Rademacher, Therneau, and Ou 2022). This model employs a continuous-time Markov process, using maximum likelihood estimation, which has been employed in similar research (Romero-Ortuno et al. 2021; Walsh et al. 2023; Yuan, Xu, and Fang 2022). We specified a model in which the timing of transitions between non-terminal states was unknown, while the exact time of death was precisely recorded (Figure 3.1). In our primary analysis, death and missing status were treated as separate absorbing states, with missing status considered an endpoint from which no further transitions are modeled, thereby facilitating model parsimony. This approach aligns with the assumption that individuals exiting the dataset are less frequent attendees or have left the system entirely. In a sensitivity analysis, we censored individuals at the time of their first missing state. We specified only transitions between adjacent states in line with naturally ordered progression and improvement. Reflecting literature supporting the reversibility of frailty, and because our eFI includes outpatient measures such as vital signs, laboratory data, and functional data from Medicare Annual Wellness visits, we allowed transitions that indicate improvement in frailty, such as from pre-frail to fit and frail to pre-frail (Lorenzo-López et al. 2019; Pajewski et al. 2019; Romero-Ortuno et al. 2021; Travers et al. 2019).

First, we fit a model without covariates to estimate transition probabilities of state transitions over one year. Next, we fit a model with covariates to assess how these factors were associated with various transition intensities, reporting findings as hazard ratios (HRs) with 95% confidence intervals. We chose covariates based on theoretical relevance, established associations in the literature (Feng et al. 2017), and evidence of unadjusted association with transitions in our analytic data set with careful evaluation to ensure minimal associations between covariates to prevent multicollinearity. We selected independent variables that were distinct from the calculation of the eFI to maintain the validity of the analysis and used a limited number of covariates due to the complex nature of multistate modeling. We used a multilevel framework to account for data that are organized at more than one level and to explore how variables at these distinct levels influenced transitions. In model 1, we examined the associations between frailty transitions and individual-level, non-modifiable demographic variables including age (55 to 64, 65 to 74, and 75+) and sex (male and female). We incorporated individual-level modifiable factors (anxiety, alcohol abuse, and smoking status) in model 2, and added area-level indicators of socioeconomic status (deprivation) and structural racism (concentration of disadvantaged populations) for model 3. Since race is a social construct serving as a proxy for exposure rather than a biological mechanism, we chose not to employ individual-level race and ethnicity identified in the EMR (Duncan and Montoya-Williams 2024). It is crucial to ensure that the use of race and ethnicity does not lead to stigmatization or inappropriate clinical decisions based purely on classification and that findings are used to develop interventions that specifically target and alleviate the factors contributing to disparities. We therefore focused on factors that provide more direct mechanisms for community-level intervention, such as deprivation and concentrated disadvantage, which provide insights into the broader social and environmental contexts in which individuals live.

Since we did not observe substantial systematic differences between those who had a geocode-able address, we assumed this data was missing completely at random and imputed missing data for ADI and ICE_{race} using multiple imputation by chained equations (Buuren and

Groothuis-Oudshoorn 2011). Coefficients and standard errors were pooled from ten imputed data sets per Rubin's Rules to derive estimates from models incorporating the ADI and ICE_{race} (Rubin, 2004).

For model validation, we compared estimated and observed prevalence and probabilities. We compared models using the Akaike Information Criterion (AIC) and used the log-likelihood ratio test to statistically compare nested models. We conducted all analyses using two-tailed tests, considering statistical significance achieved when p-values fell below 0.05.

Results

Of 125,531 individuals with a measurable eFI on October 1, 2018, followed for a median time of 4 years (384,499 total person-years), 78,506 (62.5%) remained in the cohort until the end of the observation period (Figure 3.2). Overall, 16,011 (12.7%) died within a year of their last observed eFI, and 31,014 (24.7%) went missing during the observation period.

At baseline, the cohort was predominantly female and White, non-Hispanic/Latinx, with a median age of 69 years. Most individuals were fit at the beginning of the observation period. Fit individuals were generally younger, comprising a higher proportion of males and those who were identified as White non-Hispanic/Latinx in the EMR (Table 3.1). Fit individuals had lower rates of anxiety, alcohol misuse, and smoking, were less likely to reside in areas with high deprivation and with high concentrations of disadvantaged populations, had fewer comorbidities, and had less contact with AHWFB compared to their pre-frail and frail counterparts. Conversely, individuals identified as frail at cohort entry tended to be older and had higher percentages of those identified as female and Black non-Hispanic/Latinx in the EMR. Those who were frail had higher rates of documented anxiety, alcohol misuse, and a history of smoking, resided in areas with higher deprivation and segregation, presented with a greater number of comorbidities, and had more frequent interactions AHWFB.

The prevalence of pre-frailty and frailty increased over time and was higher among those with advanced chronological age (Figure 3.3, Table 3.2). Among those without frailty at baseline, the incidence of frailty was 47.4 per 1000 person-years. The incidence rates for transitioning to pre-frailty and to frailty among those who were fit at baseline were 158 per 1000 person-years and 11.2 per 1000 person-years, respectively. The incidence of frailty among those with pre-frailty at baseline was 83.8 per 1000 person-years.

Those who were fit had a notable probability of transitioning to pre-frailty or going missing, and a smaller probability of transitioning to death. Individuals in the pre-frail state were most likely to remain stable but had varied transition pathways. Pre-frail individuals were more likely to improve to a fit state rather than transitioning to death or missing status. Similarly, frail individuals were most likely to remain in a frail state but were more likely to improve than transition to death or go missing within the next year. The probability of death increased while the probability of going missing decreased with each progressive state from fit to frail. We observed similar trends in a sensitivity analysis censoring individuals at the time of their first missing eFI, with an elevated probability of remaining fit or transitioning from fit to pre-frail. The raw number of state transitions assessed in multistate modeling also shows that most observations remain in a stable state (Table 3.4).

For transitions indicative of improvement, older age, anxiety, and smoking were independently associated with a lower hazard of improvement, in an adjusted model controlling for all other covariates (Table 3.5; Model 3). Deprivation was associated with a reduced rate of improvement from pre-frail to fit by 13% (HR = 0.87, 95% CI [0.83, 0.90]), while living in an area with a higher concentration of disadvantaged populations was associated with a reduced rate of improvement from frail to pre-frail by 9% (HR = 0.91, 95% CI [0.86, 0.97]). Overall, older age, female sex, anxiety, alcohol misuse, being a former or current smoker, and residing in areas of high deprivation and high concentration of disadvantaged populations increased the hazard of progression from fit to pre-frail and from pre-frail to frail in a fully adjusted model. For example, being 75 years of age or older was associated with a 2.07 times higher hazard (95% CI, 1.99, 2.17) of progression from pre-frail to frail compared to those who were 55-64 years of age.

Older age, being male, a recent history of alcohol misuse, and living in a deprived area were independently associated with a higher hazard of death across all frailty states holding all else constant. Smoking was associated with a higher hazard of death only for those who were fit or pre-frail. Anxiety was associated with a higher hazard of death for those who were fit and a lower hazard of death for those who were frail. Estimates were similar in a sensitivity analysis censoring individuals at the time of first missing eFI (Table 3.6).

We examined the observed temporal structure of the data and concluded that a time-homogeneous model provided a satisfactory fit that facilitated parsimony and interpretation of results (Figure 3.4, Figure 3.5). The adjusted model's estimated prevalence of states aligned well with observed prevalence indicating good model fit (Figure 3.6).

Discussion

We found that while most maintained a stable state, there was a notable probability of transitions indicative of improvement at a healthcare organization in the United States. These findings align with similar studies conducted in other countries that permitted reversibility in their designs (Lorenzo-López et al. 2019; Romero-Ortuno et al. 2021; Ye et al. 2020). We observed transition probabilities similar to those reported in a population-based survey of those aged 50 years and older living in Ireland (Romero-Ortuno et al. 2021) suggesting that a deficit-accumulation model of frailty may be applicable across diverse setting even when constructed with slight variations. Increasing prevalence of pre-frailty and frailty over time and with advanced chronological age as well as independent associations between age, sex, socioeconomic status and progressive transitions were also consistent with extant literature examining both phenotype and deficit accumulation models of frailty (Kojima et al. 2019; Romero-Ortuno et al. 2021; Walsh et al. 2023). The observation that females are more likely to progress from pre-frail to frailty while males are at a higher risk of mortality also confirms previous work suggesting that the apparent increased risk among females may be influenced by mortality bias (Hoogendijk and Dent 2022).

A primary strength of this study lies in its exploration of frailty progression using longitudinal data, which contributes to an emerging field of study (Hoogendijk and Dent 2022) aimed at understanding frailty development to elucidate pathways to frailty prevention and reversibility. Furthermore, we add to a limited body of work that has explored longitudinal transitions using routinely collected, pragmatic data within a healthcare system to construct an eFI (Walsh et al. 2023) and extend this work to unique context of the United States' healthcare environment. Another strength of this study is that while most literature has largely examined sociodemographic characteristics, we explored how individual-level modifiable factors distinct from the calculation of the eFI and relevant to older adults (anxiety, alcohol misuse, and smoking status) were associated with transitions, highlighting opportunities for intervention that may involve counseling, health education, or even physical activity to improve mental health (Andreescu and Lee 2020; Breslow et al. 2017; Hunt et al. 2023; Travers et al. 2019). In our study, recent documentation of anxiety was prevalent and was associated with reduced improvement and a higher risk of progression. Surprisingly, anxiety was associated with a higher mortality risk among fit individuals, but lower mortality among frail individuals. This paradoxical finding may be explained by the fact that individuals with anxiety often engage more frequently with healthcare services (Horenstein and Heimberg 2020), which may enable better management of acute and chronic conditions associated with frailty, thus lowering mortality risk. While less prevalent and likely under documented in structured ICD-10 data (Bradley et al. 2011; Chen and Garcia-Webb 2014), alcohol misuse was associated with increased risk of progression and death with a larger magnitude than anxiety.

This study has several limitations. While we identified similar trends in the probabilities of transitioning, we found slightly elevated probabilities of stability among those who were pre-frail an frail compared to previous research (Romero-Ortuno et al. 2021) and lower prevalence of pre-frailty and frailty, which may be attributed to methodological, population, and healthcare system differences (Walsh et al. 2023). One challenge in frailty research is the substantial variability in the tools and methods used to measure frailty, which can lead to heterogeneity of results. Our incidence and mortality rates, however, are consistent with pooled global estimates (Ofori-Asenso et al. 2019). Another limitation is that in the United States, healthcare organizations not only struggle to identify the patients for whom they are responsible for providing primary care (Riley, Love, and Wilson 2023; Turbow, Hollberg, and Ali 2021), but they also face challenges to mortality ascertainment (Lenoir et al. 2023; Wenger et al. 2024) and recognizing patients who have left the organization voluntarily, which could inflate metrics of stability and underestimate progressive transitions. To address these issues, we integrated state-level vital statistics and removed individuals upon their first missing eFI status, which was indicative of limited outpatient contact. We also recognize that the observation period coincided with the onset and continuation of the COVID-19 pandemic, which led to global declines in outpatient visits (Dupraz, Pogam, and Peytremann-Bridevaux 2022). Although patients have reported intentionally missing visits due to COVID-19 concerns, Hernandez et al. (2024) found that older adults missed fewer visits and that attendance increased as the pandemic progressed. While we cannot completely disentangle the effects of COVID-19 on missingness, progression, and death, we noted a modest increase in the rate of missingness from 2019 to 2020 for fit individuals, but relatively stable transition rates over time. We found that those who went missing were more likely to have less contact with the healthcare system and appeared to be healthier, or fit, based on structured EMR data. Lastly, while this study was conducted in a single healthcare setting limiting its generalizability, the findings are relevant to informing a pragmatic approach to preventing, delaying, or even reversing frailty. We focused on the population who would be reachable by our healthcare organization for potential interventions, such as the provision of preventive or behavioral modification services, risk stratification, or community partnerships to address social needs.

Healthcare organizations are instrumental in providing services for at-risk populations but their capabilities to address broader systemic issues such as deprivation and concentrated disadvantaged populations, which we found to be associated with progressive frailty transitions, are inherently limited. To address equity, policymakers play a crucial role in addressing community-level determinants of health that are strongly associated with poor health outcomes, including increased rates of chronic disease, higher mortality, and overall poorer quality of life (Braveman, Egerter, and Williams 2011). Improving public infrastructure like walkability and public parks, reducing crime and violence, and subsidizing community-based fitness programs in underserved areas could make physical activity more accessible, a notable factor in preventing and reversing frailty (Travers et al. 2019) Achieving true equity, however, will require more comprehensive changes, including improvements in housing, transportation, and access to quality healthcare, which collectively influence several health outcomes.

Future studies should explore additional individual-level modifiable factors and their roles in the progression and improvement of frailty, particularly among groups with chronic diseases that could benefit from targeted management strategies. Research should also further investigate the impact of socioeconomic and environmental factors that contribute to health disparities, which could be addressed through targeted policy interventions. To enhance the robustness and applicability of these findings, expanding research to include longitudinal studies across multiple and diverse healthcare settings is essential.

Conclusion

Understanding transition patterns and their associations with sociodemographic factors provides a foundational step in identifying groups likely to move into more severe states of vulnerability, from which recovery may be challenging. Analyzing the modifiable risk and protective factors associated with these transitions can inform future research and aid in the design of healthcare and policy strategies aimed at preventing or slowing the progression to frailty, or even reversing it.

References

Álvarez-Bustos, Alejandro, Jose Antonio Carnicero-Carreño, Juan Luis Sanchez-Sanchez, Francisco Javier Garcia-Garcia, Cristina Alonso-Bouzón, and Leocadio Rodríguez-Mañas. 2022. "Associations between Frailty Trajectories and Frailty Status and Adverse Outcomes in Community-Dwelling Older Adults." *Journal of Cachexia, Sarcopenia and Muscle* 13(1): 230–39. doi:10.1002/jcsm.12888.

Andreescu, Carmen, and Soyoung Lee. 2020. "Anxiety Disorders in the Elderly." In *Anxiety Disorders*, Springer, Singapore, 561–76. doi:10.1007/978-981-32-9705-0_28.

Bai, Ge, Agnieszka Szwajda, Yunzhang Wang, Xia Li, Hannah Bower, Ida K. Karlsson, Boo Johansson, et al. 2021. "Frailty Trajectories in Three Longitudinal Studies of Aging: Is the Level or the Rate of Change More Predictive of Mortality?" *Age and Ageing* 50(6): 2174–82. doi:10.1093/ageing/afab106.

Bandeen-Roche, Karen, Christopher L. Seplaki, Jin Huang, Brian Buta, Rita R. Kalyani, Ravi Varadhan, Qian-Li Xue, Jeremy D. Walston, and Judith D. Kasper. 2015. "Frailty in Older Adults: A Nationally Representative Profile in the United States." *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 70(11): 1427–34. doi:10.1093/gerona/glv133.

Bradley, Katharine A., Gwen T. Lapham, Eric J. Hawkins, Carol E. Achtmeyer, Emily C. Williams, Rachel M. Thomas, and Daniel R. Kivlahan. 2011. "Quality Concerns with Routine Alcohol Screening in VA Clinical Settings." *Journal of General Internal Medicine* 26(3): 299–306. doi:10.1007/s11606-010-1509-4.

Braveman, Paula, Susan Egerter, and David R. Williams. 2011. “The Social Determinants of Health: Coming of Age.” *Annual Review of Public Health* 32(1): 381–98. doi:10.1146/annurev-publhealth-031210-101218.

Breslow, Rosalind A., I-Jen P. Castle, Chiung M. Chen, and Barry I. Graubard. 2017. “Trends in Alcohol Consumption among Older Americans: National Health Interview Surveys, 1997–2014.” *Alcoholism, clinical and experimental research* 41(5): 976–86. doi:10.1111/acer.13365.

Buuren, Stef van, and Karin Groothuis-Oudshoorn. 2011. “Mice: Multivariate Imputation by Chained Equations in R.” *Journal of Statistical Software* 45(1): 1–67. doi:10.18637/jss.v045.i03.

Cesari, Matteo, Martin Prince, Jotheeswaran Amuthavalli Thiyagarajan, Islene Araujo De Carvalho, Roberto Bernabei, Piu Chan, Luis Miguel Gutierrez-Robledo, et al. 2016. “Frailty: An Emerging Public Health Priority.” *Journal of the American Medical Directors Association* 17(3): 188–92. doi:10.1016/j.jamda.2015.12.016.

Chamberlain, Alanna M., Lila J. Finney Rutten, Sheila M. Manemann, Barbara P. Yawn, Debra J. Jacobson, Chun Fan, Brandon R. Grossardt, Véronique L. Roger, and Jennifer L. St. Sauver. 2016. “Frailty Trajectories in an Elderly Population-Based Cohort.” *Journal of the American Geriatrics Society* 64(2): 285–92. doi:10.1111/jgs.13944.

Chambers, Brittany D., Rebecca J. Baer, Monica R. McLemore, and Laura L. Jelliffe-Pawlowski. 2019. “Using Index of Concentration at the Extremes as Indicators of Structural Racism to Evaluate the Association with Preterm Birth and Infant Mortality—California, 2011–2012.” *Journal of Urban Health: Bulletin of the New York Academy of Medicine* 96(2): 159–70. doi:10.1007/s11524-018-0272-4.

Chen, ES., and M. Garcia-Webb. 2014. “An Analysis of Free-Text Alcohol Use Documentation in the Electronic Health Record.” *Applied Clinical Informatics* 5(2): 402–15. doi:10.4338/ACI-2013-12-RA-0101.

Clegg, Andrew, Chris Bates, John Young, Ronan Ryan, Linda Nichols, Elizabeth Ann Teale, Mohammed A. Mohammed, John Parry, and Tom Marshall. 2016. “Development and Validation of an Electronic Frailty Index Using Routine Primary Care Electronic Health Record Data.” *Age and Ageing* 45(3): 353–60. doi:10.1093/ageing/afw039.

Duncan, Andrea F., and Diana Montoya-Williams. 2024. “Recommendations for Reporting Research About Racial Disparities in Medical and Scientific Journals.” *JAMA Pediatrics* 178(3): 221. doi:10.1001/jamapediatrics.2023.5718.

Dupraz, Julien, Marie-Annick Le Pogam, and Isabelle Peytremann-Bridevaux. 2022. “Early Impact of the COVID-19 Pandemic on in-Person Outpatient Care Utilisation: A Rapid Review.” *BMJ Open* 12(3): e056086. doi:10.1136/bmjopen-2021-056086.

El-Nahal, Walid. 2020. “An Overview of Medicare for Clinicians.” *Journal of General Internal Medicine* 35(12): 3702–6. doi:10.1007/s11606-019-05327-6.

Feldman, Justin M, Pamela D Waterman, Brent A Coull, and Nancy Krieger. 2015. “Spatial Social Polarisation: Using the Index of Concentration at the Extremes Jointly for Income and Race/Ethnicity to Analyse Risk of Hypertension.” *Journal of Epidemiology and Community Health* 69(12): 1199–1207. doi:10.1136/jech-2015-205728.

Feng, Zeyun, Marjolein Lugtenberg, Carmen Franse, Xinye Fang, Shanlian Hu, Chunlin Jin, and Hein Raat. 2017. “Risk Factors and Protective Factors Associated with Incident or Increase of Frailty among Community-Dwelling Older Adults: A Systematic Review of Longitudinal Studies.” *PloS One* 12(6): e0178383. doi:10.1371/journal.pone.0178383.

Ferrante, Lauren E., Margaret A. Pisani, Terrence E. Murphy, Evelyne A. Gahbauer, Linda S. Leo-Summers, and Thomas M. Gill. 2015. "Functional Trajectories among Older Persons before and after Critical Illness." *JAMA internal medicine* 175(4): 523–29. doi:10.1001/jamainternmed.2014.7889.

Fried, Linda P., Catherine M. Tangen, Jeremy Walston, Anne B. Newman, Calvin Hirsch, John Gottdiener, Teresa Seeman, et al. 2001. "Frailty in Older Adults: Evidence for a Phenotype." *The Journals of Gerontology: Series A* 56(3): M146–57. doi:10.1093/gerona/56.3.M146.

He, Wan, Daniel Goodkind, and Paul Kowal. 2016. *An Aging World: 2015*. Washington, DC: U.S. Census Bureau. https://www.census.gov/content/dam/Census/library/publications/2016/demo/p95-16-1.pdf.

Hernandez, J., Batio, S., Lovett, R. M., Wolf, M. S., & Bailey, S. C. (2024). Missed Healthcare Visits During the COVID-19 Pandemic: A Longitudinal Study. *Journal of Primary Care & Community Health, 15,* 21501319241233869. https://doi.org/10.1177/21501319241233869

Hoogendijk, Emiel O., and Elsa Dent. 2022. "Trajectories, Transitions, and Trends in Frailty among Older Adults: A Review." *Annals of Geriatric Medicine and Research* 26(4): 289–95. doi:10.4235/agmr.22.0148.

Horenstein, Arielle, and Richard G. Heimberg. 2020. "Anxiety Disorders and Healthcare Utilization: A Systematic Review." *Clinical Psychology Review* 81: 101894. doi:10.1016/j.cpr.2020.101894.

Hu, Jianhui, Amy J. H. Kind, and David Nerenz. 2018. “Area Deprivation Index Predicts Readmission Risk at an Urban Teaching Hospital.” *American Journal of Medical Quality* 33(5): 493–501. doi:10.1177/1062860617753063.

Hunt, Lauren J., Kenneth E. Covinsky, Irena Cenzer, Edie Espejo, W. John Boscardin, Heather Leutwyler, Alexandra K. Lee, and Janine Cataldo. 2023. “The Epidemiology of Smoking in Older Adults: A National Cohort Study.” *Journal of General Internal Medicine* 38(7): 1697–1704. doi:10.1007/s11606-022-07980-w.

Jackson, Christopher. 2011. “Multi-State Models for Panel Data: The Msm Package for R.” *Journal of Statistical Software* 38: 1–28. doi:10.18637/jss.v038.i08.

Kind, Amy J. H., Steve Jencks, Jane Brock, Menggang Yu, Christie Bartels, William Ehlenbach, Caprice Greenberg, and Maureen Smith. 2014. “Neighborhood Socioeconomic Disadvantage and 30 Day Rehospitalizations: An Analysis of Medicare Data.” *Annals of internal medicine* 161(11): 765–74. doi:10.7326/M13-2946.

Kind, Amy J.H., and William R. Buckingham. 2018. “Making Neighborhood-Disadvantage Metrics Accessible — the Neighborhood Atlas.” *New England Journal of Medicine* 378(26): 2456–58. doi:10.1056/NEJMp1802313.

Kojima, Gotaro, Yu Taniguchi, Steve Iliffe, Stephen Jivraj, and Kate Walters. 2019. “Transitions between Frailty States among Community-Dwelling Older People: A Systematic Review and Meta-Analysis.” *Ageing Research Reviews* 50: 81–88. doi:10.1016/j.arr.2019.01.010.

Kolle, Aurélie Tonjock, Krystina B. Lewis, Michelle Lalonde, and Chantal Backman. 2023. “Reversing Frailty in Older Adults: A Scoping Review.” *BMC Geriatrics* 23(1): 751. doi:10.1186/s12877-023-04309-y.

Kwak, Dongmin, and LaDora V. Thompson. 2020. "Frailty: Past, Present, and Future?" *Sports Medicine and Health Science* 3(1): 1–10. doi:10.1016/j.smhs.2020.11.005.

Lenoir, Kristin M., Rajib Paul, Elena Wright, Deepak Palakshappa, Nicholas M. Pajewski, Amresh Hanchate, Jaime M. Hughes, et al. 2023. "The Association of Frailty and Neighborhood Disadvantage with Emergency Department Visits and Hospitalizations in Older Adults." *Journal of General Internal Medicine*. doi:10.1007/s11606-023-08503-x.

Le-Rademacher, Jennifer G., Terry M. Therneau, and Fang-Shu Ou. 2022. "The Utility of Multistate Models: A Flexible Framework for Time-to-Event Data." *Current Epidemiology Reports* 9(3): 183–89. doi:10.1007/s40471-022-00291-y.

Lorenzo-López, Laura, Rocío López-López, Ana Maseda, Ana Buján, José L. Rodríguez-Villamil, and José C. Millán-Calenti. 2019. "Changes in Frailty Status in a Community-Dwelling Cohort of Older Adults: The VERISAÚDE Study." *Maturitas* 119: 54–60. doi:10.1016/j.maturitas.2018.11.006.

Markle-Reid, Maureen, and Gina Browne. 2003. "Conceptualizations of Frailty in Relation to Older Adults." *Journal of Advanced Nursing* 44(1): 58–68. doi:10.1046/j.1365-2648.2003.02767.x.

Marshall, Alan, James Nazroo, Gindo Tampubolon, and Bram Vanhoutte. 2015. "Cohort Differences in the Levels and Trajectories of Frailty among Older People in England." *Journal of Epidemiology and Community Health* 69(4): 316–21. doi:10.1136/jech-2014-204655.

Massey, D. S. 1996. "The Age of Extremes: Concentrated Affluence and Poverty in the Twenty-First Century." *Demography* 33(4): 395–412; discussion 413-416.

Ofori-Asenso, Richard, Ken L. Chin, Mohsen Mazidi, Ella Zomer, Jenni Ilomaki, Andrew R. Zullo, Danijela Gasevic, et al. 2019. “Global Incidence of Frailty and Prefrailty Among Community-Dwelling Older Adults: A Systematic Review and Meta-Analysis.” *JAMA Network Open* 2(8): e198398. doi:10.1001/jamanetworkopen.2019.8398.

Pajewski, Nicholas M, Kristin Lenoir, Brian J Wells, Jeff D Williamson, and Kathryn E Callahan. 2019. “Frailty Screening Using the Electronic Health Record within a Medicare Accountable Care Organization.” *Journals of Gerontology* 74(11): 1771–77. doi:https://doi.org/10.1093/gerona/glz017.

Quan, Hude, B. Li, C. M. Couris, K. Fushimi, P. Graham, P. Hider, J.-M. Januel, and V. Sundararajan. 2011. “Updating and Validating the Charlson Comorbidity Index and Score for Risk Adjustment in Hospital Discharge Abstracts Using Data From 6 Countries.” *American Journal of Epidemiology* 173(6): 676–82. doi:10.1093/aje/kwq433.

Riley, William, Kailey Love, and Charlton Wilson. 2023. “Patient Attribution—A Call for a System Redesign.” *JAMA Health Forum* 4(3): e225527. doi:10.1001/jamahealthforum.2022.5527.

Rockwood, Kenneth, and Arnold Mitnitski. 2007. “Frailty in Relation to the Accumulation of Deficits.” *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 62(7): 722–27. doi:10.1093/gerona/62.7.722.

Romero-Ortuno, Roman, Peter Hartley, Silvin P. Knight, Rose Anne Kenny, and Aisling M. O’Halloran. 2021. “Frailty Index Transitions over Eight Years Were Frequent in The Irish Longitudinal Study on Ageing.” doi:10.12688/hrbopenres.13286.1.

Rubin Donald B. 2004. *Multiple Imputation for Nonresponse in Surveys.*, New York: John Wiley and Sons.

Shi, Leiyu, and Douglas A Singh. 2021. *Delivering Health Care in America: A Systems Approach*. Jones & Bartlett Learning.

Shi, Sandra Miao, Nessa Steinberg, Gahee Oh, Brianne Olivieri-Mui, Stephanie Sison, Ellen P. McCarthy, and Dae Hyun Kim. 2023. “Change in a Claims-Based Frailty Index, Mortality, and Health Care Costs in Medicare Beneficiaries.” *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 78(7): 1198–1203. doi:10.1093/gerona/glad010.

Ströhle, Andreas, Jochen Gensichen, and Katharina Domschke. 2018. “The Diagnosis and Treatment of Anxiety Disorders.” *Deutsches Ärzteblatt International* 115(37): 611–20. doi:10.3238/arztebl.2018.0611.

Tonelli, Marcello, Natasha Wiebe, Martin Fortin, Bruce Guthrie, Brenda R Hemmelgarn, Matthew T James, Scott W Klarenbach, et al. 2015. “Methods for Identifying 30 Chronic Conditions: Application to Administrative Data.” *BMC Medical Informatics and Decision Making* 15(1). doi:10.1186/s12911-015-0155-5.

Travers, John, Roman Romero-Ortuno, Jade Bailey, and Marie-Therese Cooney. 2019. “Delaying and Reversing Frailty: A Systematic Review of Primary Care Interventions.” *British Journal of General Practice* 69(678): e61–69. doi:10.3399/bjgp18X700241.

Turbow, Sara, Julie R. Hollberg, and Mohammed K. Ali. 2021. “Electronic Health Record Interoperability: How Did We Get Here and How Do We Move Forward?” *JAMA Health Forum* 2(3): e210253. doi:10.1001/jamahealthforum.2021.0253.

Vermeiren, Sofie, Roberta Vella-Azzopardi, David Beckwée, Ann-Katrin Habbig, Aldo Scafoglieri, Bart Jansen, Ivan Bautmans, and Gerontopole Brussels Study group. 2016. “Frailty and the Prediction of Negative Health Outcomes: A Meta-Analysis.” *Journal of* *the American Medical Directors Association* 17(12): 1163.e1-1163.e17. doi:10.1016/j.jamda.2016.09.010.

U.S. Census Bureau. (2023, October 31). 2023 national population projections tables: Main series. Census.Gov. https://www.census.gov/data/tables/2023/demo/popproj/2023-summary-tables.html

Walsh, Bronagh, Carole Fogg, Scott Harris, Paul Roderick, Simon de Lusignan, Tracey England, Andrew Clegg, Sally Brailsford, and Simon D S Fraser. 2023. “Frailty Transitions and Prevalence in an Ageing Population: Longitudinal Analysis of Primary Care Data from an Open Cohort of Adults Aged 50 and over in England, 2006–2017.” *Age and Ageing* 52(5): afad058. doi:10.1093/ageing/afad058.

Welstead, Miles, Natalie D. Jenkins, Tom C. Russ, Michelle Luciano, and Graciela Muniz-Terrera. 2021. “A Systematic Review of Frailty Trajectories: Their Shape and Influencing Factors.” *The Gerontologist* 61(8): e463–75. doi:10.1093/geront/gnaa061.

Wenger, Neil S., Fernando Javier Sanz Vidorreta, Michael T. Dudley, Anne M. Walling, and Michael Hogarth. 2024. “Consequences of a Health System Not Knowing Which Patients Are Deceased.” *JAMA Internal Medicine* 184(2): 213–14. doi:10.1001/jamainternmed.2023.6428.

World Health Organization. 2015. *World Report on Ageing and Health*. Geneva, Switzerland: World Health Organization. https://apps.who.int/iris/handle/10665/186463.

Xue, Qian-Li. 2011. “The Frailty Syndrome: Definition and Natural History.” *Clinics in geriatric medicine* 27(1): 1–15. doi:10.1016/j.cger.2010.08.009.

Ye, Bo, Hao Chen, Limei Huang, Ye Ruan, Shige Qi, Yanfei Guo, Zhezhou Huang, et al. 2020. “Changes in Frailty among Community-Dwelling Chinese Older Adults and Its

Predictors: Evidence from a Two-Year Longitudinal Study." *BMC Geriatrics* 20(1): 130. doi:10.1186/s12877-020-01530-x.

Yuan, Manqiong, Chuanhai Xu, and Ya Fang. 2022. "The Transitions and Predictors of Cognitive Frailty with Multi-State Markov Model: A Cohort Study." *BMC Geriatrics* 22: 550. doi:10.1186/s12877-022-03220-2.

Table 3.1: Baseline characteristics at the time of cohort entry

	Overall	Fit	Pre-frail	Frail
N	125531	55936	54426	15169
Years of follow up, median [IQR]	4 [2, 4]	4 [1, 4]	4 [3, 4]	4 [2, 4]
Age years, median [IQR]	68.6 [62.1, 75.8]	66.5 [61.0, 73.1]	69.5 [62.9, 76.5]	73.8 [66.3, 81.8]
Age years, n (%)				
55-64	40533 (32.3)	21917 (39.2)	15775 (29.0)	2841 (18.7)
65-74	46876 (37.3)	21285 (38.1)	20745 (38.1)	4846 (31.9)
75+	38122 (30.4)	12734 (22.8)	17906 (32.9)	7482 (49.3)
Sex, n (%)				
Female	71615 (57.0)	30882 (55.2)	31178 (57.3)	9555 (63.0)
Male	53916 (43.0)	25054 (44.8)	23248 (42.7)	5614 (37.0)
Race/Ethnicity, n (%)				
Black non-Hispanic/Latinx	15964 (12.7)	5801 (10.4)	7932 (14.6)	2231 (14.7)
Hispanic/Latinx	2327 (1.9)	1174 (2.1)	943 (1.7)	210 (1.4)
Other[a] non-Hispanic/Latinx	2400 (1.9)	1242 (2.2)	968 (1.8)	190 (1.3)
White non-Hispanic/Latinx	104824 (83.5)	47713 (85.3)	44575 (81.9)	12536 (82.6)
Unknown	16 (0.0)	6 (0.0)	8 (0.0)	2 (0.0)
Body mass index, median [IQR]	29.0 [25.4, 33.4]	28.2 [25.0, 31.9]	29.6 [25.7, 34.3]	30.4 [25.7, 35.7]
ADI, median [IQR]	70 [54, 81]	67 [51, 79]	71 [56, 81]	72 [59, 83]
Deprivation, n (%)				
High (ADI>85)	19118 (15.2)	7007 (12.5)	9200 (16.9)	2911 (19.2)
Mid/low	104979 (83.6)	48239 (86.2)	44643 (82.0)	12097 (79.7)
Missing	1434 (1.1)	690 (1.2)	583 (1.1)	161 (1.1)
ICE_{race} median [IQR]	0.74 [0.45, 0.90]	0.75 [0.51, 0.90]	0.73 [0.42, 0.89]	0.72 [0.35, 0.89]
Disadvantaged populations, n (%)				
High concentration ($ICE_{race}<0$)	13125 (10.5)	4626 (8.3)	6392 (11.7)	2107 (13.9)
Mid/low	111649 (88.9)	50909 (91.0)	47754 (87.7)	12986 (85.6)
Missing	757 (0.6)	401 (0.7)	280 (0.5)	76 (0.5)
Anxiety, n (%)	25582 (20.4)	7210 (12.9)	12882 (23.7)	5490 (36.2)
Alcohol misuse, n (%)	2834 (2.3)	663 (1.2)	1549 (2.8)	622 (4.1)
Smoking status, n (%)				
Never	63943 (50.9)	33253 (59.4)	24915 (45.8)	5775 (38.1)
Former or Current	61588 (49.1)	22683 (40.6)	29511 (54.2)	9394 (61.9)
CCI, median [IQR]	1 [0, 3]	0 [0, 1]	2 [1, 3]	4 [2, 6]
CVD, n (%)	13758 (11.0)	2736 (4.9)	6747 (12.4)	4275 (28.2)
CHF, n (%)	10620 (8.5)	1145 (2.0)	4755 (8.7)	4720 (31.1)
COPD, n (%)	29211 (23.3)	6399 (11.4)	15154 (27.8)	7658 (50.5)
Diabetes, n (%)	32731 (26.1)	6697 (12.0)	17928 (32.9)	8106 (53.4)

Malignancy, n (%)[b]	19852 (15.8)	7451 (13.3)	9133 (16.8)	3268 (21.5)
Encounter count, prior year, median [IQR]	27 [13, 50]	16 [8, 28]	34 [20, 57]	69 [43, 113]
Outpatient visit count, prior year, median [IQR]	3 [2, 6]	2 [1, 4]	4 [2, 7]	8 [4, 12]

Note. All group comparisons yielded p-values less than 0.001 based on a Chi-square test for categorical variables and a Kruskal-Wallis test for non-normally distributed numeric variables. Abbreviations are as follows: Interquartile range (IQR), Charlson comorbidity index (CCI), cerebrovascular disease (CVD), congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), index of concentration at the extremes (ICE).

[a]Other is inclusive of categories in the EMR labeled as American Indian or Alasa Native, Asian, multiracial, Native Hawaiian or Other Pacific Islander, and Other (not further specified).

[b]Excludes malignant neoplasm of skin.

Table 3.2: Prevalence of frailty states within cohort across time

Year	2018	2019	2020	2021	2022
Total n	125,531	112,152	98,381	87,634	78,506
Fit, n (%)	55936 (44.6%)	45701 (40.7%)	38129 (38.8%)	32351 (36.9%)	26625 (33.9%)
Pre-frail, n (%)	54426 (43.4%)	50960 (45.4%)	45252 (46.0%)	40833 (46.6%)	37930 (48.3%)
Frail, n (%)	15169 (12.1%)	15491 (13.8%)	15000 (15.2%)	14450 (16.5%)	13951 (17.8%)

Note. Year indicates October first of that year.

Table 3.3: Estimated probabilities of state transitions for a one-year period

From state	To state	Missing state model, probability (95% CI)	Censored model, probability (95% CI)
Fit	Fit	0.693 (0.691, 0.695)	0.797 (0.795, 0.799)
	Pre-frail	0.151 (0.149, 0.152)	0.173 (0.171, 0.175)
	Frail	0.009 (0.009, 0.009)	0.010 (0.010, 0.011)
	Death	0.019 (0.019, 0.020)	0.020 (0.019, 0.020)
	Missing	0.128 (0.126, 0.129)	
Pre-frail	Fit	0.118 (0.117, 0.120)	0.124 (0.123, 0.125)
	Pre-frail	0.716 (0.714, 0.718)	0.751 (0.749, 0.753)
	Frail	0.084 (0.083, 0.085)	0.088 (0.087, 0.089)
	Death	0.037 (0.036, 0.038)	0.037 (0.036, 0.038)
	Missing	0.044 (0.043, 0.045)	
Frail	Fit	0.016 (0.016, 0.016)	0.016 (0.016, 0.017)
	Pre-frail	0.189 (0.186, 0.192)	0.193 (0.190, 0.196)
	Frail	0.680 (0.676, 0.683)	0.694 (0.690, 0.697)
	Death	0.097 (0.095, 0.099)	0.097 (0.095, 0.099)
	Missing	0.018 (0.017, 0.020)	

Note. Estimated from multistate models with time of first missing eFI as an absorbing state or censored.

Table 3.4: Raw number of state transitions analyzed in a multistate model

	To				
From	Fit	Pre-frail	Frail	Death	Missing
Fit	119388	27323	576	3145	21685
Pre-frail	23058	135878	17526	6747	8262
Frail	360	11774	40790	6119	1067

Table 3.5: Associations between covariates and transition intensities for a multistate model with missing as an absorbing state

	Unadjusted HR (95% CI)	Model 1 HR (95% CI)	Model 2 HR (95% CI)	Model 3 HR (95% CI)
Improvement				
Pre-frail to fit				
Age 65-74	**0.84 (0.81,0.87)**	**0.84 (0.82,0.87)**	**0.82 (0.80,0.85)**	**0.82 (0.79,0.85)**
Age 75+	**0.70 (0.67,0.72)**	**0.70 (0.67,0.72)**	**0.67 (0.65,0.69)**	**0.66 (0.64,0.69)**
Male	1.00 (0.97,1.03)	1.00 (0.97,1.02)	**1.04 (1.01,1.07)**	**1.03 (1.00,1.06)**
Anxiety	**0.91 (0.88,0.94)**		**0.89 (0.86,0.92)**	**0.89 (0.86,0.92)**
Alcohol misuse	0.90 (0.82,1.00)		0.91 (0.82,1.00)	0.92 (0.84,1.02)
Smoking	**0.79 (0.77,0.81)**			**0.77 (0.75,0.79)**
High deprivation	**0.86 (0.83,0.90)**			**0.87 (0.83,0.90)**
Concentrated disadvantage	**0.92 (0.88,0.96)**			0.97 (0.92,1.01)
Frail to pre-frail				
Age 65-74	**0.88 (0.84,0.93)**	**0.88 (0.84,0.92)**	0.86 (0.82,0.90)	**0.86 (0.81,0.90)**
Age 75+	**0.73 (0.69,0.77)**	**0.73 (0.69,0.77)**	0.70 (0.66,0.73)	**0.69 (0.66,0.73)**
Male	1.00 (0.96,1.03)	1.00 (0.96,1.04)	1.00 (0.96,1.04)	1.00 (0.96,1.04)
Anxiety	**0.92 (0.88,0.96)**		0.88 (0.85,0.92)	**0.88 (0.84,0.92)**
Alcohol misuse	0.98 (0.88,1.09)		0.94 (0.85,1.05)	0.95 (0.86,1.06)
Smoking	**0.90 (0.87,0.94)**			**0.88 (0.84,0.91)**
High deprivation	0.98 (0.94,1.03)			0.99 (0.94,1.04)
Concentrated disadvantage	**0.94 (0.89,0.99)**			**0.91 (0.86,0.97)**
Progression				
Fit to pre-frail				
Age 65-74	**1.22 (1.18,1.25)**	**1.22 (1.18,1.25)**	**1.24 (1.20,1.27)**	**1.24 (1.21,1.28)**
Age 75+	**1.45 (1.41,1.50)**	**1.45 (1.41,1.50)**	**1.47 (1.43,1.52)**	**1.48 (1.44,1.53)**
Male	0.98 (0.96,1.00)	0.98 (0.96,1.00)	**0.96 (0.93,0.98)**	**0.96 (0.94,0.98)**
Anxiety	**1.36 (1.31,1.40)**		**1.38 (1.33,1.43)**	**1.39 (1.34,1.44)**
Alcohol misuse	**1.60 (1.45,1.76)**		**1.48 (1.34,1.64)**	**1.43 (1.30,1.59)**
Smoking	**1.33 (1.30,1.36)**		**1.30 (1.27,1.33)**	**1.29 (1.26,1.32)**
High deprivation	**1.21 (1.16,1.25)**			**1.11 (1.07,1.15)**
Concentrated disadvantage	**1.29 (1.24,1.35)**			**1.24 (1.19,1.30)**
Pre-frail to Frail				
Age 65-74	**1.25 (1.20,1.31)**	**1.26 (1.20,1.31)**	**1.30 (1.24,1.36)**	**1.31 (1.26,1.37)**
Age 75+	**1.91 (1.83,1.99)**	**1.91 (1.83,1.99)**	**2.04 (1.95,2.13)**	**2.07 (1.99,2.17)**
Male	**0.92 (0.89,0.95)**	**0.92 (0.89,0.95)**	**0.89 (0.86,0.92)**	**0.90 (0.87,0.93)**
Anxiety	**1.28 (1.24,1.33)**		**1.32 (1.28,1.37)**	**1.34 (1.29,1.39)**
Alcohol misuse	**1.29 (1.18,1.41)**		**1.35 (1.23,1.48)**	**1.30 (1.19,1.43)**
Smoking	**1.30 (1.26,1.34)**		**1.36 (1.32,1.41)**	**1.35 (1.31,1.39)**
High deprivation	**1.16 (1.11,1.20)**			**1.09 (1.05,1.14)**
Concentrated disadvantage	**1.22 (1.16,1.27)**			**1.22 (1.17,1.29)**

Table 3.6: Associations between covariates and transition intensities for a multistate model with missing as an absorbing state (continued)

Death				
Fit to death				
Age 65-74	**1.65 (1.45,1.88)**	**1.65 (1.45,1.87)**	**1.67 (1.47,1.89)**	**1.68 (1.48,1.91)**
Age 75+	**6.18 (5.51,6.93)**	**6.16 (5.49,6.90)**	**6.14 (5.47,6.89)**	**6.17 (5.50,6.92)**
Male	**1.55 (1.43,1.67)**	**1.55 (1.44,1.68)**	**1.36 (1.26,1.48)**	**1.37 (1.26,1.48)**
Anxiety	**0.99 (0.88,1.11)**		**1.23 (1.09,1.39)**	**1.24 (1.10,1.39)**
Alcohol misuse	**2.31 (1.78,2.99)**		**2.15 (1.65,2.80)**	**2.07 (1.59,2.69)**
Smoking	**2.10 (1.94,2.27)**		**1.87 (1.73,2.03)**	**1.87 (1.72,2.02)**
High deprivation	**1.41 (1.27,1.57)**			**1.33 (1.19,1.49)**
Concentrated disadvantage	**1.20 (1.05,1.37)**			1.12 (0.97,1.29)
Pre-frail to death				
Age 65-74	**1.37 (1.25,1.50)**	**1.36 (1.24,1.49)**	**1.40 (1.28,1.53)**	**1.41 (1.29,1.54)**
Age 75+	**3.52 (3.24,3.82)**	**3.53 (3.25,3.83)**	**3.71 (3.42,4.04)**	**3.77 (3.46,4.10)**
Male	**1.46 (1.39,1.54)**	**1.49 (1.41,1.57)**	**1.36 (1.29,1.44)**	**1.37 (1.30,1.45)**
Anxiety	**0.83 (0.78,0.89)**		0.99 (0.92,1.06)	0.99 (0.92,1.07)
Alcohol misuse	**1.69 (1.47,1.94)**		**1.91 (1.66,2.19)**	**1.86 (1.62,2.15)**
Smoking	**1.34 (1.27,1.41)**		**1.32 (1.25,1.40)**	**1.32 (1.25,1.39)**
High deprivation	**1.12 (1.05,1.20)**			**1.14 (1.06,1.23)**
Concentrated disadvantage	1.04 (0.96,1.13)			1.09 (1.00,1.20)
Frail to death				
Age 65-74	**1.19 (1.08,1.32)**	**1.20 (1.08,1.33)**	**1.20 (1.08,1.33)**	**1.21 (1.09,1.34)**
Age 75+	**2.42 (2.21,2.66)**	**2.44 (2.23,2.67)**	**2.46 (2.24,2.70)**	**2.48 (2.26,2.72)**
Male	**1.43 (1.36,1.51)**	**1.44 (1.37,1.52)**	**1.39 (1.32,1.47)**	**1.40 (1.33,1.48)**
Anxiety	**0.79 (0.74,0.83)**		**0.92 (0.86,0.97)**	**0.92 (0.87,0.98)**
Alcohol misuse	**1.19 (1.04,1.36)**		**1.36 (1.18,1.55)**	**1.35 (1.18,1.55)**
Smoking	1.03 (0.98,1.09)		1.03 (0.98,1.09)	1.03 (0.97,1.09)
High deprivation	1.01 (0.95,1.08)			**1.11 (1.03,1.19)**
Concentrated disadvantage	**0.92 (0.85,0.99)**			0.98 (0.90,1.07)

Note. HR indicates hazard ratio and CI indicates confidence interval. HRs with confidence intervals indicating significant results are bolded. Reference groups for subset of independent variables: Age (55-64), Sex-Male (Female), High deprivation (mid/low deprivation), Concentrated disadvantage (mid to low concentrated disadvantage).

Table 3.7: Associations between covariates and transition intensities for a multistate model with censoring at the time of first missing eFI state

	Unadjusted HR (95% CI)	Model 1 HR (95% CI)	Model 2 HR (95% CI)	Model 3 HR (95% CI)
Improvement				
Pre-frail to fit				
Age 65-74	**0.84 (0.82,0.87)**	**0.84 (0.82,0.87)**	**0.83 (0.80,0.85)**	**0.82 (0.80,0.85)**
Age 75+	**0.69 (0.67,0.72)**	**0.69 (0.67,0.72)**	**0.66 (0.64,0.69)**	**0.66 (0.63,0.68)**
Male	1.00 (0.97,1.03)	1.00 (0.97,1.02)	**1.04 (1.02,1.07)**	**1.04 (1.01,1.07)**
Anxiety	**0.91 (0.88,0.94)**		**0.90 (0.87,0.93)**	**0.89 (0.86,0.92)**
Alcohol misuse	**0.88 (0.80,0.97)**		**0.89 (0.80,0.98)**	0.90 (0.82,1.00)
Smoking	**0.78 (0.76,0.80)**		**0.76 (0.74,0.78)**	**0.76 (0.74,0.78)**
High deprivation	**0.86 (0.83,0.89)**			**0.87 (0.83,0.90)**
Concentrated disadvantage	0.92 (0.88,0.96)			0.96 (0.92,1.01)
Frail to pre-frail				
Age 65-74	**0.88 (0.84,0.93)**	**0.88 (0.84,0.93)**	**0.86 (0.82,0.91)**	**0.86 (0.82,0.90)**
Age 75+	**0.73 (0.70,0.77)**	**0.73 (0.70,0.77)**	**0.70 (0.66,0.73)**	**0.69 (0.66,0.73)**
Male	0.99 (0.96,1.03)	0.99 (0.96,1.03)	1.00 (0.96,1.04)	0.99 (0.96,1.03)
Anxiety	**0.92 (0.88,0.95)**		**0.88 (0.85,0.92)**	**0.88 (0.84,0.92)**
Alcohol misuse	0.98 (0.88,1.08)		0.94 (0.85,1.05)	0.95 (0.85,1.05)
Smoking	**0.90 (0.87,0.94)**		**0.87 (0.84,0.90)**	**0.87 (0.84,0.91)**
High deprivation	0.98 (0.94,1.03)			0.99 (0.94,1.04)
Concentrated disadvantage	0.94 (0.89,0.99)			**0.91 (0.86,0.97)**
Progression				
Fit to pre-frail				
Age 65-74	**1.21 (1.18,1.25)**	**1.21 (1.18,1.25)**	**1.23 (1.20,1.27)**	**1.24 (1.20,1.28)**
Age 75+	**1.47 (1.42,1.51)**	**1.47 (1.42,1.51)**	**1.49 (1.44,1.54)**	**1.50 (1.45,1.55)**
Male	0.98 (0.95,1.00)	0.98 (0.95,1.00)	**0.95 (0.93,0.98)**	**0.95 (0.93,0.98)**
Anxiety	**1.35 (1.31,1.40)**		**1.38 (1.33,1.42)**	**1.39 (1.34,1.43)**
Alcohol misuse	**1.64 (1.49,1.81)**		**1.52 (1.38,1.68)**	**1.47 (1.33,1.62)**
Smoking	**1.35 (1.32,1.38)**		**1.32 (1.29,1.35)**	**1.31 (1.28,1.34)**
High deprivation	**1.21 (1.17,1.25)**			**1.12 (1.07,1.16)**
Concentrated disadvantage	**1.29 (1.24,1.35)**			**1.25 (1.19,1.30)**
Pre-frail to Frail				
Age 65-74	**1.25 (1.20,1.31)**	**1.25 (1.20,1.31)**	**1.29 (1.24,1.35)**	**1.31 (1.25,1.37)**
Age 75+	**1.91 (1.83,1.99)**	**1.91 (1.83,1.99)**	**2.03 (1.95,2.12)**	**2.07 (1.98,2.16)**
Male	**0.92 (0.89,0.95)**	**0.92 (0.90,0.95)**	**0.89 (0.86,0.91)**	**0.90 (0.87,0.93)**
Anxiety	**1.28 (1.24,1.33)**		**1.32 (1.28,1.37)**	**1.34 (1.29,1.39)**
Alcohol misuse	**1.30 (1.18,1.42)**		**1.35 (1.24,1.48)**	**1.31 (1.19,1.43)**
Smoking	**1.31 (1.27,1.35)**		**1.37 (1.33,1.41)**	**1.36 (1.31,1.40)**
High deprivation	**1.16 (1.11,1.20)**			**1.09 (1.05,1.14)**
Concentrated disadvantage	**1.22 (1.16,1.27)**			**1.23 (1.17,1.29)**

Table 3.8: Associations between covariates and transition intensities for a multistate model with censoring at the time of first missing eFI state (continued)

Death				
Fit				
Age 65-74	**1.66 (1.46,1.89)**	**1.66 (1.46,1.89)**	**1.69 (1.48,1.92)**	**1.70 (1.50,1.93)**
Age 75+	**6.12 (5.45,6.87)**	**6.12 (5.45,6.87)**	**6.09 (5.43,6.84)**	**6.14 (5.47,6.90)**
Male	**1.56 (1.44,1.69)**	**1.56 (1.45,1.69)**	**1.38 (1.27,1.49)**	**1.38 (1.27,1.50)**
Anxiety	0.99 (0.88,1.12)		**1.23 (1.09,1.39)**	**1.24 (1.10,1.39)**
Alcohol misuse	**2.23 (1.72,2.90)**		**2.09 (1.60,2.73)**	**2.02 (1.55,2.64)**
Smoking	**2.07 (1.92,2.24)**		**1.85 (1.71,2.00)**	**1.84 (1.70,1.99)**
High deprivation	**1.40 (1.26,1.56)**			**1.32 (1.18,1.48)**
Concentrated disadvantage	**1.20 (1.05,1.37)**			1.11 (0.96,1.29)
Pre-frail				
Age 65-74	**1.37 (1.25,1.50)**	**1.37 (1.25,1.50)**	**1.41 (1.28,1.54)**	**1.42 (1.29,1.55)**
Age 75+	**3.52 (3.24,3.82)**	**3.53 (3.25,3.84)**	**3.72 (3.42,4.05)**	**3.77 (3.47,4.10)**
Male	**1.46 (1.39,1.54)**	**1.49 (1.41,1.57)**	**1.37 (1.29,1.44)**	**1.38 (1.30,1.46)**
Anxiety	**0.83 (0.78,0.89)**		0.98 (0.92,1.06)	**0.99 (0.92,1.06)**
Alcohol misuse	**1.68 (1.46,1.93)**		**1.89 (1.65,2.18)**	**1.85 (1.61,2.13)**
Smoking	**1.34 (1.27,1.41)**		**1.32 (1.25,1.40)**	**1.32 (1.24,1.39)**
High deprivation	**1.12 (1.05,1.20)**			**1.14 (1.06,1.23)**
Concentrated disadvantage	1.04 (0.96,1.13)			1.09 (1.00,1.20)
Frail				
Age 65-74	**1.20 (1.09,1.33)**	**1.20 (1.08,1.33)**	**1.20 (1.09,1.33)**	**1.21 (1.09,1.34)**
Age 75+	**2.43 (2.22,2.67)**	**2.44 (2.22,2.67)**	**2.46 (2.24,2.70)**	**2.48 (2.26,2.72)**
Male	**1.44 (1.37,1.51)**	**1.44 (1.37,1.52)**	**1.40 (1.32,1.48)**	**1.40 (1.33,1.48)**
Anxiety	**0.79 (0.74,0.83)**		**0.92 (0.86,0.97)**	**0.92 (0.86,0.98)**
Alcohol misuse	**1.18 (1.03,1.35)**		**1.35 (1.18,1.55)**	**1.35 (1.18,1.55)**
Smoking	1.03 (0.98,1.09)		1.03 (0.98,1.09)	1.03 (0.98,1.09)
High deprivation	1.01 (0.95,1.08)			**1.11 (1.03,1.19)**
Concentrated disadvantage	**0.92 (0.85,0.99)**			0.99 (0.91,1.07)

Note. HR indicates hazard ratio and CI indicates confidence interval. HRs with confidence intervals indicating significant results are bolded. Reference groups for subset of independent variables: Age (55-64), Sex-Male (Female), High deprivation (mid/low deprivation), Concentrated disadvantage (mid to low concentrated disadvantage).

Figure 3.1

Structure of multistate model

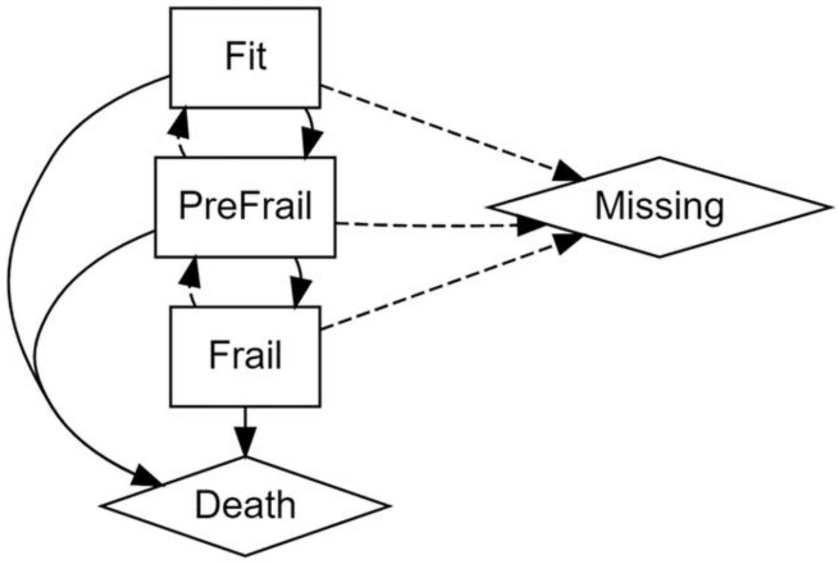


Figure 3.2

Alluvial plot of transitions over four years of observations from baseline

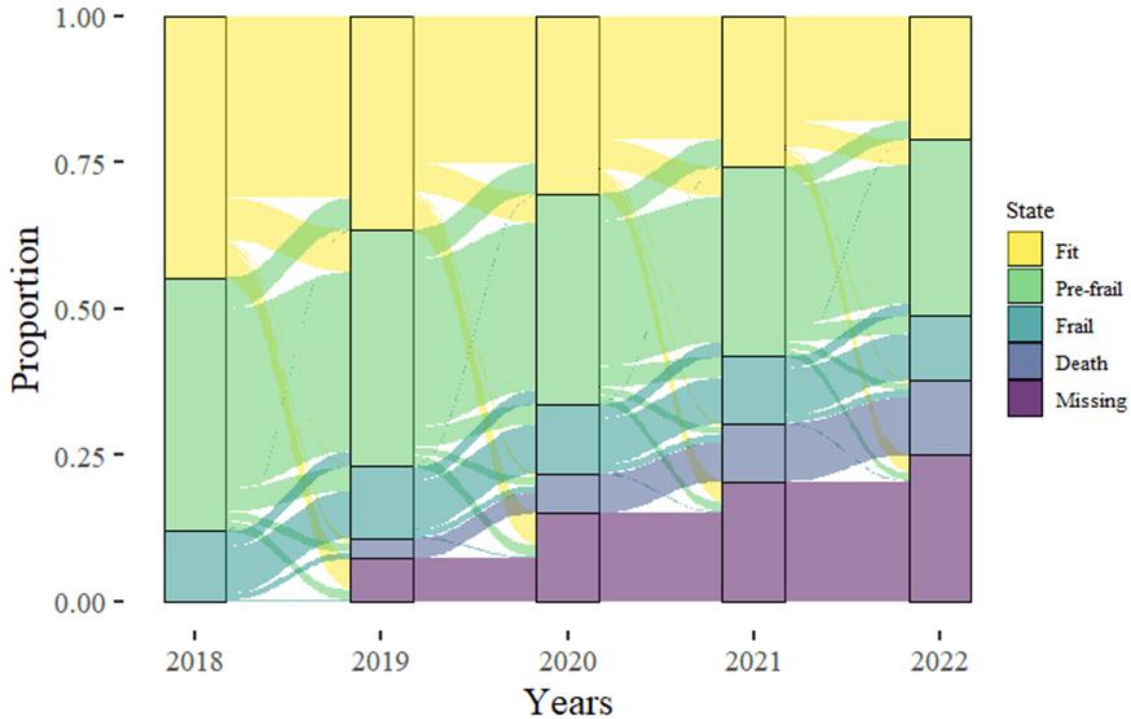


Figure 3.3

Prevalence of frailty across time overall and by age at baseline

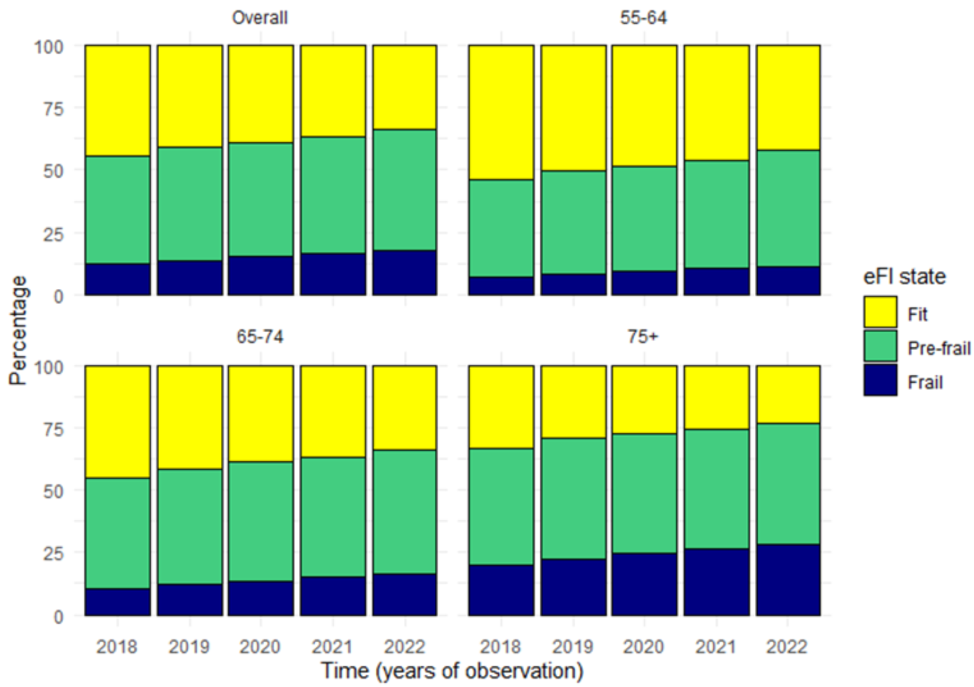
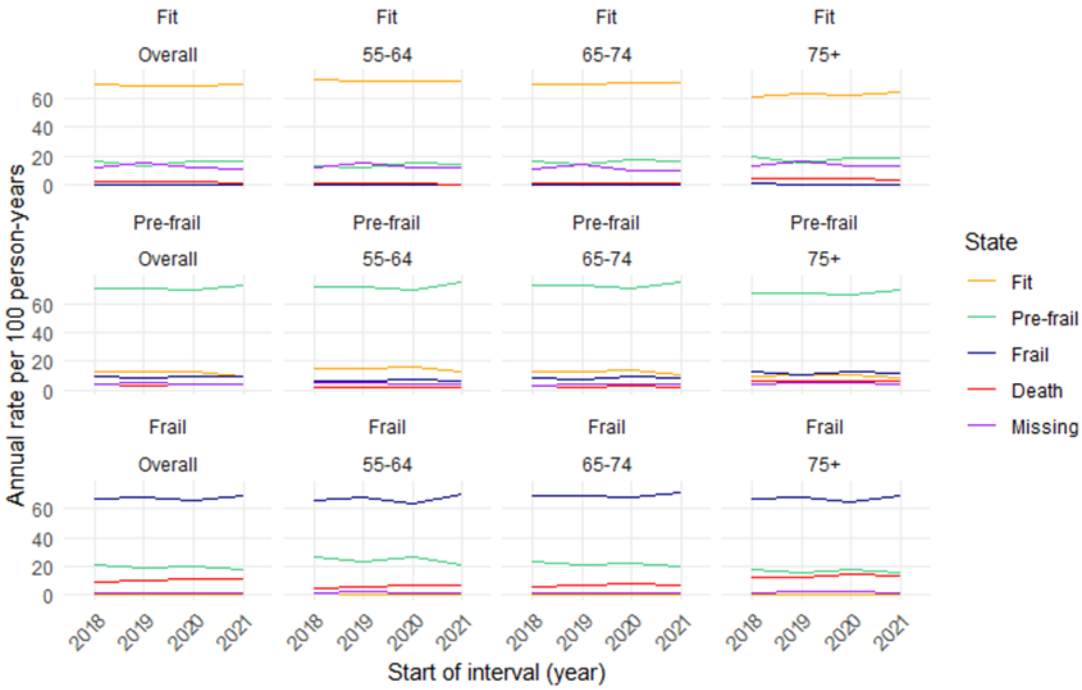


Figure 3.4

Annual rate of state transitions over time by interval state and age at the beginning of each interval



Note. Denominator includes those transitioning to a missing state.

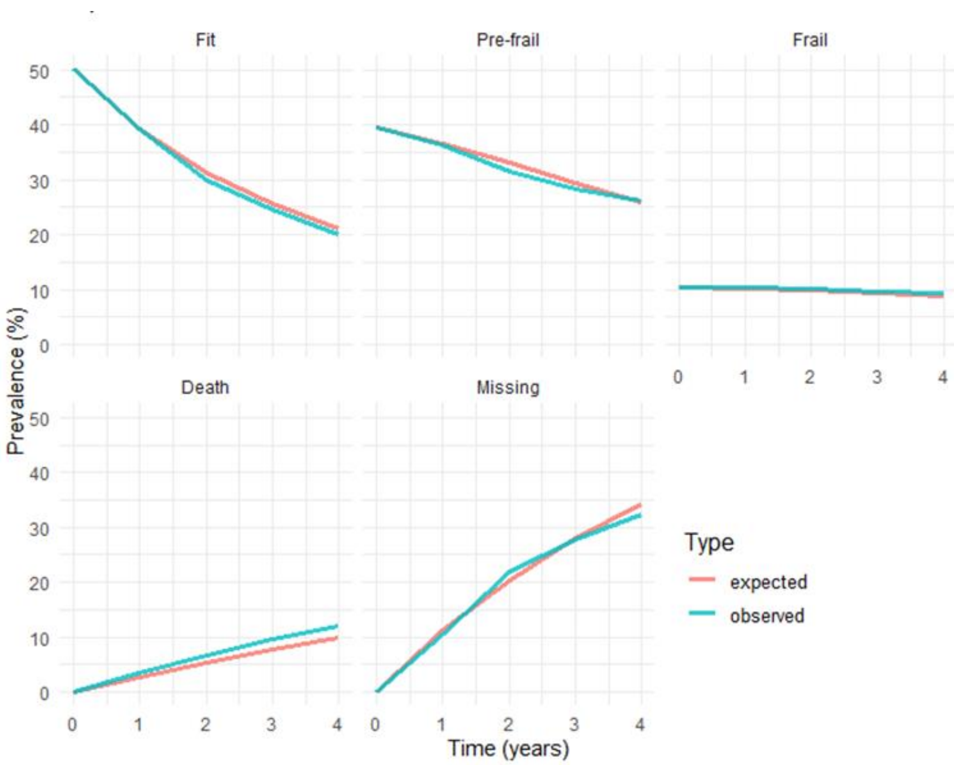
Figure 3.5

Annual rate of state transitions over time by interval state and age at the beginning of each interval

Note. Denominator excludes those transitioning to a missing state and only displays state changes.

Figure 3.6

Observed vs. expected prevalence of states over time estimated from a multivariable multistate model with missing status as an absorbing state



CHAPTER 4: URBAN AND RURAL DIFFERENCES IN FRAILTY AND ASSOCIATED FACTORS

Introduction

In the United States, 16.8% of the population was aged 65 and older in 2020 (Caplan & Rabe, 2023). The proportion of older adults is projected to increase to comprise a quarter of the population by 2060, making healthy aging and health promotion for older adults a national priority (Fulmer et al., 2021; Healthy People 2030, 2022; U.S. Census Bureau, 2023). Understanding the development of frailty, an internationally recognized indicator of increased vulnerability, can inform strategies to prevent or delay frailty onset thereby averting a state of elevated risk linked to numerous adverse outcomes (Clegg et al., 2013; Dent et al., 2016; Hoogendijk & Dent, 2022). Elucidating the factors associated with frailty development, including the context in which one lives, can shape clinical care approaches to identify at-risk populations to mitigate the risk of adverse events (Dent et al., 2023). Healthcare organizations can play a role in supporting the health of older adults through the use of an electronic Frailty Index (eFI) to inform their population management strategies and risk-stratification methods (Callahan et al., 2021; Clegg et al., 2016; Lenoir et al., 2023; Pajewski et al., 2019). Not only is there limited work regarding frailty development using pragmatic longitudinal data from the electronic medical record (EMR) (Hoogendijk & Dent, 2022), but a there is little work exploring urban-rural differences in frailty and its development (Huang et al., 2020; Walsh et al., 2023). Considering differences between those residing in urban and rural settings may influence how we implement screening and interventions to serve these populations most effectively.

Geography, and rurality in particular, has been identified as a crucial determinant of health disparities, with rural areas experiencing numerous disadvantages (Lutfiyya et al., 2012). Urban and rural populations differ in several aspects, which has implications for health outcomes, healthcare access, and the potential for interventions that can be implemented by healthcare organizations. In the United States, rural populations are predominantly White with a higher proportion of older adults and have lower socioeconomic and educational levels compared to the more racially and ethnically diverse and younger populations living in urban areas (Pew Research Center, 2018). Rural populations are at heightened risk for morbidity and mortality but face structural barriers to healthy aging including fewer healthcare facilities and providers (Curtin & Spencer, 2021; Douthit et al., 2015). This can lead to less engagement with preventive care or delayed care, which can exacerbate of chronic or acute health issues (Decker & Weaver, 2021; Douthit et al., 2015; Zhang et al., 2020). Alcohol misuse and smoking rates, which are modifiable individual-level risk factors that disproportionately affect older adults, are higher in rural areas (Breslow et al., 2017; Dixon & Chartier, 2016; Hunt et al., 2023; Parker et al., 2022). Rural populations also experience disparities in mental health (Coughlin et al., 2019). Those living in urban areas also experience barriers to care even in the presence of abundant physician supply (Wolfe et al., 2020), and health disparities in urban areas often stem from factors such as race, socioeconomic status, and residential concentration of disadvantaged populations (Alicea-Alvarez et al., 2016; Chambers et al., 2019).

As frailty prevalence increases (Kwak & Thompson, 2020), studying transitions between frailty states becomes essential to understanding who is at risk of developing this heightened state of vulnerability before it occurs to inform preventive interventions an enhance older adults' health (Hoogendijk & Dent, 2022). Given the differences between those living in urban and rural settings highlighted above, geographic setting may be a critical factor in understanding the development and progression of frailty. Literature highlights a substantial gap in understanding how frailty develops across urban and rural settings, with most studies using cross-sectional data that do not capture the dynamic progression of frailty. Several studies in other countries document a higher prevalence of frailty among those living in urban areas (He et al., 2019; Rodriguez et al., 2018; Sinclair et al., 2022) while others have found frailty to be associated with rural status (Jang et al., 2016; Seo et al., 2021; Song et al., 2007; Yu et al., 2012). A longitudinal study found that urban populations were at higher risk of progression while rural populations had a higher hazard of death (Walsh et al., 2023). Our objective was to fill a gap in the literature by examining if prevalence and progression varied among urban and rural populations engaged at a large healthcare organization in the United States and to determine if associations between demographic, individual- and area-level factors were modified by rural status.

Methods

Setting and Population

This retrospective observational study included adults aged 55 and older with a primary care provider affiliated with Atrium Health Wake Forest Baptist (AHWFB) and a measurable eFI state (fit, pre-frail, or frail) in the electronic medical record (EMR) (Epic, Verona, WI) on October 1, 2018. Since AHWFB provides primary, specialty, and hospital-based care across a 24-county region in western North Carolina and into southwest Virginia, we limited our analysis to individuals whose structured addresses data indicated residency within these states. This study was approved by the Wake Forest University School of Medicine Institutional Review Board and the University of North Carolina Institutional Review Board.

Data Structure

We calculated longitudinal electronic Frailty Index (eFIs) measurements annually from October 2018 through October 2022. Although the precise timing of transitions between states was unknown between these discrete intervals, the dates of death were recorded exactly. A prerequisite for a calculable eFI was that the individual had at least two outpatient visits in the past two years, ensuring inclusion of those actively engaged with the healthcare system and excluding those with minimal contact or insufficient structured data. Given our goal to assess the risk of progression among patients regularly accessing primary care at AHWFB, we excluded eFI measures and deaths occurring after an individual's first missing eFI to avoid making assumptions about individuals' health status with limited data.

Key Variables

Since 2019, AHWFB has implemented a weekly calculation of the electronic Frailty Index (eFI) for patients aged 55 and older, the methodology of which has been described (Pajewski et al., 2019). Continuous eFI measure can be categorized into three states: fit ($eFI < 0.10$), pre-frail ($0.10 < eFI \leq 0.21$), and frail ($eFI > 0.21$). For our analysis, we extracted demographic and clinical variables from structured data in AHWFB's EMR. Sex was recorded in the EMR as male or female, and age groups were categorized (55 to 64, 65 to 74, and 75 years or older), reflecting both the data distribution and common age classifications. Comorbidities, along with specific conditions such as anxiety and alcohol misuse, were identified through International Classification of Diseases, Tenth Revision (ICD-10) codes documented in the problem list and during patient encounters, with a two-year look-back period relative to each date of eFI calculation (Quan et al., 2011; Ströhle et al., 2018; Tonelli et al., 2015). Smoking status (Never and Former/Current) was ascertained from structured social data collected at each encounter. Structured address data were linked to the 2022 Area Deprivation Index at the block group level and categorized based on a threshold linked to adverse outcomes (high deprivation, $ADI > 85$) (Hu et al., 2018; Kind et al., 2014). We used Index of Concentration at the Extremes for race (ICE_{race}) at the block group level to quantify the degree of concentration of disadvantaged populations, using it as a proxy for structural racism and adverse exposures (Chambers et al., 2019). We dichotomized this as high concentrated disadvantage ($ICE_{race} < 0$) and mid/low concentrated disadvantage ($ICE_{rac}e \geq 0$) in lieu of typical quantile categorization given that this continuous measure was skewed toward higher concentrations of advantaged populations (White non-Hispanic/Latinx). We classified urban and rural status of individuals based on the U.S. Census Bureau's 2020 decennial designation using shapefiles from 2022 (US Census Bureau, 2023). Mortality data from the EMR was supplemented by North Carolina vital statistics, which AHWFB's Clinical and Translational Science Institute matches to patient data using a deterministic algorithm.

Statistical Analysis

We report the prevalence of frailty over time and employed multistate modeling using the "msm" package in R to explore transitions between frailty states for urban and rural populations attending AHWFB (Jackson, 2011; Le-Rademacher et al., 2022). We specified our model to account for eFI measurements collected at discrete annual time points between which the exact moments of transition between non-terminal states were unknown. We captured the approximate timing of death. We treated both death and the first interval at which an eFI was missing as distinct absorbing states (Figure 4.1) based on the assumption that individuals no longer appearing in the dataset might represent individuals with fragmented care across organizations or those who had discontinued or limited engagement with AHWFB. We restricted model transitions to those between adjacent frailty states, reflecting a natural order of progression (fit to pre-frail and pre-frail to frail) and permitted transitions indicative of improvement (pre-frail to fit and frail to pre-frail) consistent with studies affirming the potential for frailty reversal (Lorenzo-López et al., 2019; Romero-Ortuno et al., 2021; Travers et al., 2019). We first specified an unadjusted model, focusing solely on urban and rural status as a single covariate to establish baseline transition probabilities for each group. Next, we employed covariates in our model to explore how associations with transitions varied by urban-rural status. These covariates were selected based on established and theoretical associations (He et al., 2019; Ho et al., 2021; Hoogendijk & Dent, 2022; Xu et al., 2021) and included demographic (age and sex), individual-level modifiable factors (anxiety, alcohol use, smoking status), and area-level factors (deprivation and concentrated disadvantage). Urban and rural status and covariates were time-varying, except sex. The "msm" package did not support the separation of baseline hazards by stratified groups. To overcome this limitation and explore how the association between covariates and transitions differed between urban and rural patients, we created interaction terms for each covariate with urban-rural status. This method assumes that the associations between covariates and transitions are different for urban and rural status and is essentially equivalent to employing a stratified model. Given the goal of emulating a stratification analysis, we reported hazard ratios (HR) and 95% confidence intervals (CI) for urban and rural strata. We also reported the additional effect of rural status for each covariate to determine whether associations statistically differed between urban and rural residence, indicating if rural status modified the associations. We imputed missing observations for urban and rural status and deprivation for modeling, which we assumed to be missing completely at random, using multivariate imputation by chained equations (Buuren & Groothuis-Oudshoorn, 2011).

We considered that the predominance of urban observations could potentially bias the results, amplifying urban-specific associations and possibly underrepresenting the dynamics unique to rural settings. To address this imbalance, we conducted a sensitivity analysis where we selected a random subset of individuals with urban observations to match the number of rural observations more closely, recognizing the limitations of how individuals' residences varied over time. For model validation, we assessed the fit by comparing estimated versus observed prevalence and score residuals. We evaluated different models based on the Akaike Information Criterion (AIC) and used the log-likelihood ratio test for comparing nested models. All analyses were performed with two-tailed tests, with p-values less than 0.05 considered statistically significant.

Results

We identified 125,531 individuals with a measurable eFI on October 1, 2018, who had an AHWFB-affiliated primary care provider and lived in North Carolina or Virginia. Of these 124,774 (99.4%) were able to be linked to geographic residence data from the U.S. Census Bureau, with 74,191 (59.5%) residing in an urban area and 50,583 (40.5%) residing in a rural area at baseline (Table 4.1). At baseline, this cohort was predominantly female and White, with a median age of 69 years. Those living in rural areas were slightly younger and more likely to be male and White. While the proportions of those with anxiety were similar, those living in rural areas had slightly elevated smoking rates and lower rates of alcohol misuse. Those living in rural areas had a higher median ADI, but fewer lived in areas of high deprivation and in areas with a high concentration of disadvantaged populations. The Charlson Comorbidity Index was similar between urban and rural individuals with variations in the proportions of specific comorbidities. Rural patients engaged less frequently with the healthcare system.

The prevalence of pre-frailty and frailty increased over time for both groups (Table 4.2, Figure 4.2). While pre-frailty prevalence was similar across urban and rural residents, the prevalence of frailty was higher for those living in urban areas. Urban and rural patients were both most likely to remain in a stable state compared to transitioning within a year across all states. A visualization of transition probabilities estimated at four years showed that urban patients were more likely to experience progressive transitions (Figure 4.3). Rural patients had slightly elevated probabilities of death and a higher probability of going missing across states.

Older age, having documented anxiety, being a former or current smoker and living in areas of high deprivation were independently associated with a lower hazard of improvement from pre-frail to fit states for both urban and rural populations holding all else constant (Table 4.3), and these associations were not modified by rural status. Living in an area with a high concentration of disadvantaged populations was associated with a 49% higher potential for improvement from a pre-frail to fit state for rural residents only (HR = 1.49, 95% CI [1.13, 1.97]), and this estimate was statistically higher for the rural stratum compared to the urban stratum (HR = 1.58, 95% CI [1.19, 2.10]). Older age and smoking were independently associated with a lower hazard of improvement from frail to pre-frail for both strata. Being male was associated with a 7% higher hazard of improvement for those with a rural residence (HR = 1.07, 95% CI [>1.00, 1.14]), while having anxiety was associated with a 16% reduced hazard of improvement from pre-frail to fit for those residing in an urban area (HR = 0.84, 95% CI [0.75, 0.93]); Rural status modified the associations between sex and anxiety with transitioning from pre-frail to fit.

For progressive transitions, older age, anxiety, alcohol misuse, previous or current smoking status, and living in a deprived area were independently associated with higher hazard of progressing from fit to pre-frail for urban and rural residents in a fully adjusted model. Rural status statistically modified the association between older age (75 years and older) compared to those who were 55 to 64 years, which was lower for rural residents (HR = 0.93, 95% CI [0.88, <1.00]). Although anxiety was associated with an elevated hazard of progressing from fit to pre-frail status for both strata, the estimate was higher for those living in rural areas (HR = 1.09, 95% CI [1.02, 1.17]). Rural status did not modify associations between any of the covariates and progression from pre-frail to frail states. Older age, being female, anxiety, alcohol misuse, and previous or current smoking status were associated with a higher hazard of transitioning from pre-frail to frail for urban and rural residents. While alcohol misuse conferred a higher hazard of progressing from pre-frail to frail for rural residents only, this was not statistically different from the urban estimate (HR = 1.15, 95% CI [0.95, 1.41]).

Holding all else constant, older age was associated with transitions to death with larger magnitudes for less vulnerable states. Males were also at higher risk for death across states and the geographic residence. Current or former smoking status was associated with a higher hazard of death among those who were fit or pre-frail for both urban and rural residents. For transitions from fit to death, anxiety and living in an area with a high concentration of disadvantaged population were associated with a higher hazard of death for rural residents, while alcohol misuse and living in an area of high deprivation were associated with death for urban residents. Rural status, however, only statistically modified associations for living in areas of deprivation and concentrated disadvantage for transitions from fit to death. Alcohol misuse conferred a higher hazard of death from a pre-frail state for both strata. Living in an area of high deprivation was modified by rural status (HR = 0.82, 95% CI [0.70, 0.96]) and was associated with an elevated hazard of death for urban residents only (HR = 1.23, 95% CI [1.01, 1.51] from a pre-frail state. The association between older age (≥75) and transitioning from pre-frail state to death was reduced for rural residents (HR = 0.84, 95% CI [0.71, <1.00]). While alcohol misuse, anxiety, and living in an area of high deprivation were associated with a higher hazard of death for those with frailty for rural residents only, these estimates were not statistically distinct from estimates within the urban strata. Rural status did not modify any of the associations between covariates and the transition from a frail state to death. In a sensitivity analysis in which we randomly selected a similar number of urban observations to the number of rural observations, we observed similar probabilities (Table 4.4) and only minor differences among a few variables with confidence intervals close to one (Table 4.5).

We found that a model with interaction terms for each of the covariates and urban-rural status provided a better fit (AIC=812,113) despite the introduction of numerous additional parameters, compared to a model employing this variable as a covariate in the adjusted model (AIC=812,155). Furthermore, the model incorporating a high concentration of disadvantaged populations provided a superior fit to a model without (AIC = 812,274, χ^2 (20) = 200.7, $p<0.001$). Observed and estimated prevalence of states over time aligned well.

Discussion

Our findings that those residing in urban areas were more likely to experience progressive transitions while rural residents were more likely to transition to death is in line with longitudinal research in at a healthcare organization in England (Walsh et al., 2023). A novel contribution of our research includes the observation that rural patients were more likely to go missing. Our finding of higher prevalence of frailty in an urban setting aligns with some international research (He et al., 2019; Rodriguez et al., 2018; Sinclair et al., 2022) and contrasts with other studies demonstrating or hypothesizing that individuals living in rural areas are more frail (Huang et al., 2020; Jang et al., 2016; Seo et al., 2021; Xu et al., 2021; Yu et al., 2012). Additionally, our results corroborate research indicating that age and mental health are significant risk factors for frailty among rural populations (Xu et al., 2021).

While being female and of advanced age are non-modifiable factors related to progression from pre-frailty to frailty and may be useful for risk-stratification, modifiable individual-level factors offer valuable insights for interventions to prevent, delay, or even reverse frailty. The observed association between alcohol use and progressive transitions, particularly in rural areas, highlights a potential target for tailored interventions. This does not suggest focusing interventions solely on alcohol misuse in rural populations but rather integrating these efforts into a broader program that also addresses factors like smoking and anxiety. Given the differences in how certain factors operate in urban versus rural settings, it is crucial to adapt interventions to the cultural, social, and economic contexts of these populations. For instance, rural interventions should account for access challenges unique to these areas. Behavioral counseling, treatment programs, health education and promotion, and encouragement of physical activity are all viable strategies that healthcare organizations can implement to address these modifiable risk factors (Botwright et al., 2023; Golechha, 2016; Ströhle et al., 2018; Travers et al., 2019).

Area-level variables primarily affected transitions between less vulnerable states. In particular, living in a deprived area affected progression from fit to pre-frailty. Public health and policy interventions targeting social determinants of health are likely to be most effective prior to a certain threshold of health deterioration (Andermann, 2016; Daniel et al., 2018). As individuals enter more vulnerable health states, interacting chronic conditions and reduced physiological resilience make recovery increasingly difficult, and interventions targeting social needs, or any single health aspect might not be strong enough to counteract the momentum of declining health. Interestingly, living in areas with a high concentration of disadvantaged populations was associated with improvement from pre-frail to fit states for rural populations, which is counterintuitive considering the structural racism and inequities leading to significant health disparities (Braveman et al., 2022). This might reflect a specific dynamic in rural settings where community involvement and social support, often stronger in rural and minority communities, play a significant role in health outcomes (Hardy et al., 2024; Hart et al., 2001). This is similar to research with paradoxical findings in which rural Black populations living in North Carolina exhibited superior mental health than their rural White counterparts despite experiencing racial disparities (Efird et al., 2023; Kothari et al., 2016).

A strength of this study is that it is the first, to our knowledge, which examines urban and rural differences in frailty progression and associated factors using routinely collected healthcare data in the United States. We not only add to a limited field examining frailty progression using longitudinal data (Hoogendijk & Dent, 2022), but also addresses the notable gap in understanding frailty differences across urban and rural settings. Additionally, this research was conducted at a large healthcare organization that provides numerous levels of care and is located in a state with the third-largest rural population in the U.S (U.S. Census Bureau, 2022). This setting offered a rich dataset conducive to complex modeling within a real-world context.

This study has several limitations. In the United States, healthcare organizations often encounter significant challenges in identifying their primary care responsibilities, especially given a competitive healthcare environment in which patients can obtain care across multiple healthcare organizations (Riley et al., 2023; Turbow et al., 2021). While we limited the analytic cohort to individuals residing within a reasonable catchment area and those with an assigned primary care provider, this approach may not have fully mitigated the issues of care fragmentation and data incompleteness stemming from patients receiving services outside of AHWFB's network. Consequently, this could lead to patients appearing healthier than they actually are. This situation is exacerbated by a lack of interoperability among healthcare systems, which hinders these organizations' ability to obtain a comprehensive view of a patient's health history (Reisman, 2017). However, our analysis leveraged structured data that a healthcare organization would typically use to inform decision-making processes, as integrating data from multiple sources can be challenging. We also integrated vital statistics to account for healthcare organizations' limitations in mortality ascertainment (Wenger et al., 2024). A limitation concerning generalizability is that our study only included individuals within our system; the urban and rural patients we serve and analyzed may not represent broader urban and rural populations, particularly those who lack access to care. Our baseline descriptive statistics deviate from typical urban and rural comparisons. For example, while we know those living in rural areas are generally older and with more comorbidities (Curtin & Spencer, 2021; Douthit et al., 2015), we found a larger proportion of those aged 75 and older among urban individuals and variability in the distribution of major comorbidities across geographic residence. Despite these differences, we noted several consistencies with typical urban/rural patterns, such as a higher proportion of White individuals in rural areas, fewer interactions with the healthcare system, and a higher probability of mortality among rural patients (García et al., 2024; Nuako et al., 2022; Pew Research Center, 2018). Additionally, we noted estimates that were significant within a single stratum, but that were not statistically modified by rural status, which is seemingly paradoxical. This can occur when a covariate has a significant effect in one stratum due to a larger sample size or higher variability, but the overall interaction effect is not significant because the differences between strata are not large enough to detect. In the future, increasing the sample size or weighting transitions similarly across strata could help clarify the observed differences. Despite this limitation, the significant findings within each stratum highlight important trends and potential areas for intervention within specific populations. Lastly, caution must be exercised when interpreting area-level variables, as the ecological fallacy warns against assuming that aggregate data accurately reflect individual characteristics. While these conclusions may not necessarily apply to individual patients, they do offer valuable insights into the structural barriers that may influence patient health outcomes.

This exploratory study paves the way for hypothesis-driven research aimed at strategically enhancing healthcare delivery and patient outcomes in both urban and rural environments. We have only begun to uncover the complexities of urban and rural dynamics, and further research is necessary to do delve into what granular components related to this geographical level contribute to these findings. Exploration of prevalence and how frailty progresses at a population level is also warranted. Investigating frailty across larger and more representative population and in diverse healthcare environments is crucial to lend validity to our findings and guide the development of interventions that are effectively tailored to meet specific community needs. In general, there is a critical need for further research to identify which interventions are most effective at delaying and preventing frailty (Travers et al. 2019) and how we might tailor these to different geographic settings. Additionally, qualitative research, such as detailed interviews or focus groups that explore patients' experiences before a transition may provide deeper insights into the factors influencing frailty progression and improvement.

Conclusion

In conclusion, our study reveals differences in frailty progression between urban and rural populations, suggesting that healthcare organizations might consider these differences when developing targeted interventions, population management, and risk stratification strategies. The higher prevalence of frailty observed in urban settings, alongside the greater mortality risk associated with rural environments, underscores the necessity for tailored healthcare approaches that address the specific challenges and needs of each group. Addressing modifiable factors such as alcohol use, smoking, and anxiety may enhance the effectiveness of these strategies. To optimize patient outcomes, we should further explore the unique social, economic, and cultural contexts of urban and rural populations.

References

Alicea-Alvarez, N., Reeves, K., Rabelais, E., Huang, D., Ortiz, M., Burroughs, T., & Jones, N. (2016). Impacting Health Disparities in Urban Communities: Preparing Future Healthcare Providers for "Neighborhood-Engaged Care" Through a Community Engagement Course Intervention. Journal of Urban Health: Bulletin of the New York Academy of Medicine, 93(4), 732–743. https://doi.org/10.1007/s11524-016-0057-6

Andermann, A. (2016). Taking action on the social determinants of health in clinical practice: A framework for health professionals. CMAJ: Canadian Medical Association Journal, 188(17–18), E474. https://doi.org/10.1503/cmaj.160177

Botwright, S., Sutawong, J., Kingkaew, P., Anothaisintawee, T., Dabak, S. V., Suwanpanich, C., Promchit, N., Kampang, R., & Isaranuwatchai, W. (2023). Which interventions for alcohol use should be included in a universal healthcare benefit package? An umbrella review of targeted interventions to address harmful drinking and dependence. BMC Public Health, 23(1), 382. https://doi.org/10.1186/s12889-023-15152-6

Braveman, P. A., Arkin, E., Proctor, D., Kauh, T., & Holm, N. (2022). Systemic And Structural Racism: Definitions, Examples, Health Damages, And Approaches to Dismantling. Health Affairs, 41(2), 171–178. https://doi.org/10.1377/hlthaff.2021.01394

Breslow, R. A., Castle, I.-J. P., Chen, C. M., & Graubard, B. I. (2017). Trends in Alcohol Consumption among Older Americans: National Health Interview Surveys, 1997–2014. Alcoholism, Clinical and Experimental Research, 41(5), 976–986. https://doi.org/10.1111/acer.13365

Buuren, S. van, & Groothuis-Oudshoorn, K. (2011). mice: Multivariate Imputation by Chained Equations in R. Journal of Statistical Software, 45(1), Article 1. https://doi.org/10.18637/jss.v045.i03

Callahan, K. E., Clark, C. J., Edwards, A. F., Harwood, T. N., Williamson, J. D., Moses, A. W., Willard, J. J., Cristiano, J. A., Meadows, K., Hurie, J., High, K. P., Meredith, J. W., & Pajewski, N. M. (2021). Automated frailty screening at-scale for pre-operative risk stratification using the electronic frailty index. Journal of the American Geriatrics Society, 69(5), 1357–1362. https://doi.org/10.1111/jgs.17027

Caplan, Z., & Rabe, M. (2023). The older population: 2020 (C2020BR-07; 2020 Census Briefs). U.S. Census Bureau. https://www2.census.gov/library/publications/decennial/2020/census-briefs/c2020br-07.pdf

Chambers, B. D., Baer, R. J., McLemore, M. R., & Jelliffe-Pawlowski, L. L. (2019). Using Index of Concentration at the Extremes as Indicators of Structural Racism to Evaluate the Association with Preterm Birth and Infant Mortality—California, 2011–2012. Journal of Urban Health: Bulletin of the New York Academy of Medicine, 96(2), 159–170. https://doi.org/10.1007/s11524-018-0272-4

Clegg, A., Bates, C., Young, J., Ryan, R., Nichols, L., Ann Teale, E., Mohammed, M. A., Parry, J., & Marshall, T. (2016). Development and validation of an electronic frailty index using routine primary care electronic health record data. Age and Ageing, 45(3), 353–360. https://doi.org/10.1093/ageing/afw039

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. Lancet, 381(9868), 752–762. https://doi.org/10.1016/S0140-6736(12)62167-9

Coughlin, S. S., Clary, C., Johnson, J. A., Berman, A., Heboyan, V., Benevides, T., Moore, J., & George, V. (2019). Continuing Challenges in Rural Health in the United States. Journal of Environment and Health Sciences, 5(2), 90–92.

Curtin, S., & Spencer, M. R. (2021). Trends in Death Rates in Urban and Rural Areas: United States, 1999–2019 (NCHS Data Brief 417; NCHS Data Brief). National Center for Health Statistics (U.S). https://doi.org/10.15620/cdc:109049

Daniel, H., Bornstein, S. S., Kane, G. C., & for the Health and Public Policy Committee of the American College of Physicians. (2018). Addressing Social Determinants to Improve Patient Care and Promote Health Equity: An American College of Physicians Position Paper. Annals of Internal Medicine, 168(8), 577–578. https://doi.org/10.7326/M17-2441

Decker, A., & Weaver, R. (2021). Health and Social Determinants Associated with Delay of Health Care Among Rural Older Adults. Innovation in Aging, 5(Suppl 1), 210–211. https://doi.org/10.1093/geroni/igab046.813

Dent, E., Hanlon, P., Sim, M., Jylhävä, J., Liu, Z., Vetrano, D. L., Stolz, E., Pérez-Zepeda, M. U., Crabtree, D. R., Nicholson, C., Job, J., Ambagtsheer, R. C., Ward, P. R., Shi, S. M., Huynh, Q., & Hoogendijk, E. O. (2023). Recent developments in frailty identification, management, risk factors and prevention: A narrative review of leading journals in geriatrics and gerontology. Ageing Research Reviews, 91, 102082. https://doi.org/10.1016/j.arr.2023.102082

Dent, E., Kowal, P., & Hoogendijk, E. O. (2016). Frailty measurement in research and clinical practice: A review. European Journal of Internal Medicine, 31, 3–10. https://doi.org/10.1016/j.ejim.2016.03.007

Dixon, M. A., & Chartier, K. G. (2016). Alcohol Use Patterns Among Urban and Rural Residents. Alcohol Research: Current Reviews, 38(1), 69–77.

Douthit, N., Kiv, S., Dwolatzky, T., & Biswas, S. (2015). Exposing some important barriers to health care access in the rural USA. Public Health, 129(6), 611–620. https://doi.org/10.1016/j.puhe.2015.04.001

Efird, C. R., Matthews, D. D., Muessig, K. E., Barrington, C. L., Metzl, J. M., & Lightfoot, A. F. (2023). Rural and nonrural racial variation in mentally unhealthy days: Findings from the behavioral risk factor surveillance system in North Carolina, 2015–2019. SSM - Mental Health, 3, 100199. https://doi.org/10.1016/j.ssmmh.2023.100199

Fulmer, T., Reuben, D. B., Auerbach, J., Fick, D. M., Galambos, C., & Johnson, K. S. (2021). Actualizing Better Health and Health Care for Older Adults. Health Affairs, 40(2), 219–225. https://doi.org/10.1377/hlthaff.2020.01470

García, M. C., Rossen, L. M., Matthews, K., Guy, G., Trivers, K. F., Thomas, C. C., Schieb, L., & Iademarco, M. F. (2024). Preventable Premature Deaths from the Five Leading Causes of Death in Nonmetropolitan and Metropolitan Counties, United States, 2010–2022. MMWR. Surveillance Summaries, 73(2), 1–11. https://doi.org/10.15585/mmwr.ss7302a1

Golechha, M. (2016). Health Promotion Methods for Smoking Prevention and Cessation: A Comprehensive Review of Effectiveness and the Way Forward. International Journal of Preventive Medicine, 7, 7. https://doi.org/10.4103/2008-7802.173797

Hardy, R. Y., Boch, S. J., Davenport, M. A., Chavez, L. J., & Kelleher, K. J. (2024). Rural-urban differences in social and emotional protective factors and their association with child health and flourishing. The Journal of Rural Health: Official Journal of the American

Rural Health Association and the National Rural Health Care Association, 40(2), 314–325. https://doi.org/10.1111/jrh.12802

Hart, H. M., McAdams, D. P., Hirsch, B. J., & Bauer, J. J. (2001). Generativity and Social Involvement among African Americans and White Adults. Journal of Research in Personality, 35(2), 208–230. https://doi.org/10.1006/jrpe.2001.2318

He, B., Ma, Y., Wang, C., Jiang, M., Geng, C., Chang, X., Ma, B., & Han, L. (2019). Prevalence and Risk Factors for Frailty Among Community-Dwelling Older People in China: A Systematic Review and Meta-Analysis. The Journal of Nutrition, Health and Aging, 23(5), 442–450. https://doi.org/10.1007/s12603-019-1179-9

Healthy People 2030. (2022, February 6). Older adults—Healthy People 2030. Health.Gov. https://health.gov/healthypeople/objectives-and-data/browse-objectives/older-adults

Ho, L. Y. W., Cheung, D. S. K., Kwan, R. Y. C., Wong, A. S. W., & Lai, C. K. Y. (2021). Factors associated with frailty transition at different follow-up intervals: A scoping review. Geriatric Nursing, 42(2), 555–565. https://doi.org/10.1016/j.gerinurse.2020.10.005

Hoogendijk, E. O., & Dent, E. (2022). Trajectories, Transitions, and Trends in Frailty among Older Adults: A Review. Annals of Geriatric Medicine and Research, 26(4), 289–295. https://doi.org/10.4235/agmr.22.0148

Hu, J., Kind, A. J. H., & Nerenz, D. (2018). Area Deprivation Index Predicts Readmission Risk at an Urban Teaching Hospital. American Journal of Medical Quality, 33(5), 493–501. https://doi.org/10.1177/1062860617753063

Huang, C.-Y., Lee, W.-J., Lin, H.-P., Chen, R.-C., Lin, C.-H., Peng, L.-N., & Chen, L.-K. (2020). Epidemiology of frailty and associated factors among older adults living in rural communities in Taiwan. Archives of Gerontology and Geriatrics, 87, 103986. https://doi.org/10.1016/j.archger.2019.103986

Hunt, L. J., Covinsky, K. E., Cenzer, I., Espejo, E., Boscardin, W. J., Leutwyler, H., Lee, A. K., & Cataldo, J. (2023). The Epidemiology of Smoking in Older Adults: A National Cohort Study. Journal of General Internal Medicine, 38(7), 1697–1704. https://doi.org/10.1007/s11606-022-07980-w

Jackson, C. (2011). Multi-State Models for Panel Data: The msm Package for R. Journal of Statistical Software, 38, 1–28. https://doi.org/10.18637/jss.v038.i08

Jang, I.-Y., Jung, H.-W., Lee, C. K., Lee, Y. S., Kim, K., Kim, K. W., Oh, H., Ji, M.-Y., Lee, E., & Kim, D. H. (2016). Rural and Urban Disparities in Frailty and Aging-Related Health Conditions in Korea. Journal of the American Geriatrics Society, 64(4), 908–911. https://doi.org/10.1111/jgs.14074

Kind, A. J. H., Jencks, S., Brock, J., Yu, M., Bartels, C., Ehlenbach, W., Greenberg, C., & Smith, M. (2014). Neighborhood socioeconomic disadvantage and 30 day rehospitalizations: An analysis of Medicare data. Annals of Internal Medicine, 161(11), 765–774. https://doi.org/10.7326/M13-2946

Kothari, C. L., Paul, R., Dormitorio, B., Ospina, F., James, A., Lenz, D., Baker, K., Curtis, A., & Wiley, J. (2016). The interplay of race, socioeconomic status and neighborhood residence upon birth outcomes in a high black infant mortality community. SSM - Population Health, 2, 859–867. https://doi.org/10.1016/j.ssmph.2016.09.011

Kwak, D., & Thompson, L. V. (2020). Frailty: Past, present, and future? Sports Medicine and Health Science, 3(1), 1–10. https://doi.org/10.1016/j.smhs.2020.11.005

Lenoir, K. M., Paul, R., Wright, E., Palakshappa, D., Pajewski, N. M., Hanchate, A., Hughes, J. M., Gabbard, J., Wells, B. J., Dulin, M., Houlihan, J., & Callahan, K. E. (2023). The Association of Frailty and Neighborhood Disadvantage with Emergency Department Visits and Hospitalizations in Older Adults. Journal of General Internal Medicine. https://doi.org/10.1007/s11606-023-08503-x

Le-Rademacher, J. G., Therneau, T. M., & Ou, F.-S. (2022). The Utility of Multistate Models: A Flexible Framework for Time-to-Event Data. Current Epidemiology Reports, 9(3), 183–189. https://doi.org/10.1007/s40471-022-00291-y

Lorenzo-López, L., López-López, R., Maseda, A., Buján, A., Rodríguez-Villamil, J. L., & Millán-Calenti, J. C. (2019). Changes in frailty status in a community-dwelling cohort of older adults: The VERISAÚDE study. Maturitas, 119, 54–60. https://doi.org/10.1016/j.maturitas.2018.11.006

Lutfiyya, M. N., McCullough, J. E., Haller, I. V., Waring, S. C., Bianco, J. A., & Lipsky, M. S. (2012). Rurality as a Root or Fundamental Social Determinant of Health. Disease-a-Month, 58(11), 620–628. https://doi.org/10.1016/j.disamonth.2012.08.005

Nuako, A., Liu, J., Pham, G., Smock, N., James, A., Baker, T., Bierut, L., Colditz, G., & Chen, L.-S. (2022). Quantifying rural disparity in healthcare utilization in the United States: Analysis of a large midwestern healthcare system. PLOS ONE, 17(2), e0263718. https://doi.org/10.1371/journal.pone.0263718

Pajewski, N. M., Lenoir, K., Wells, B. J., Williamson, J. D., & Callahan, K. E. (2019). Frailty screening using the electronic health record within a Medicare accountable care organization. Journals of Gerontology, 74(11), 1771–1777. https://doi.org/10.1093/gerona/glz017

Parker, M. A., Weinberger, A. H., Eggers, E. M., Parker, E. S., & Villanti, A. C. (2022). Trends in Rural and Urban Cigarette Smoking Quit Ratios in the US From 2010 to 2020. JAMA Network Open, 5(8), e2225326. https://doi.org/10.1001/jamanetworkopen.2022.25326

Pew Research Center. (2018). What unites and divides urban, suburban and rural communities. Pew Research Center. https://www.pewresearch.org/wp-content/uploads/sites/20/2018/05/Pew-Research-Center-Community-Type-Full-Report-FINAL.pdf

Quan, H., Li, B., Couris, C. M., Fushimi, K., Graham, P., Hider, P., Januel, J.-M., & Sundararajan, V. (2011). Updating and Validating the Charlson Comorbidity Index and Score for Risk Adjustment in Hospital Discharge Abstracts Using Data From 6 Countries. American Journal of Epidemiology, 173(6), 676–682. https://doi.org/10.1093/aje/kwq433

Reisman, M. (2017). EHRs: The challenge of making electronic data usable and interoperable. Pharmacy and Therapeutics, 42(9), 572–575.

Riley, W., Love, K., & Wilson, C. (2023). Patient Attribution—A Call for a System Redesign. JAMA Health Forum, 4(3), e225527. https://doi.org/10.1001/jamahealthforum.2022.5527

Rodriguez, J. J. L., Prina, A. M., Acosta, D., Guerra, M., Huang, Y., Jacob, K. S., Jimenez-Velasquez, I. Z., Salas, A., Sosa, A. L., Williams, J. D., Jotheeswaran, A. T., Acosta, I., Liu, Z., & Prince, M. J. (2018). The Prevalence and Correlates of Frailty in Urban and Rural Populations in Latin America, China, and India: A 10/66 Population-Based Survey. Journal of the American Medical Directors Association, 19(4), 287-295.e4. https://doi.org/10.1016/j.jamda.2017.09.026

Romero-Ortuno, R., Hartley, P., Knight, S. P., Kenny, R. A., & O'Halloran, A. M. (2021). Frailty index transitions over eight years were frequent in The Irish Longitudinal Study on Ageing (4:63). HRB Open Research. https://doi.org/10.12688/hrbopenres.13286.1

Seo, Y., Kim, M., Shim, H., & Won, C. W. (2021). Differences in the Association of Neighborhood Environment with Physical Frailty Between Urban and Rural Older Adults: The Korean Frailty and Aging Cohort Study (KFACS). Journal of the American Medical Directors Association, 22(3), 590-597.e1. https://doi.org/10.1016/j.jamda.2020.09.044

Sinclair, D. R., Maharani, A., Chandola, T., Bower, P., Hanratty, B., Nazroo, J., O'Neill, T. W., Tampubolon, G., Todd, C., Wittenberg, R., Matthews, F. E., & Pendleton, N. (2022). Frailty among Older Adults and Its Distribution in England. The Journal of Frailty & Aging, 11(2), 163–168. https://doi.org/10.14283/jfa.2021.55

Song, X., MacKnight, C., Latta, R., Mitnitski, A. B., & Rockwood, K. (2007). Frailty and survival of rural and urban seniors: Results from the Canadian Study of Health and Aging. Aging Clinical and Experimental Research, 19(2), 145–153. https://doi.org/10.1007/BF03324681

Ströhle, A., Gensichen, J., & Domschke, K. (2018). The Diagnosis and Treatment of Anxiety Disorders. Deutsches Ärzteblatt International, 115(37), 611–620. https://doi.org/10.3238/arztebl.2018.0611

Tonelli, M., Wiebe, N., Fortin, M., Guthrie, B., Hemmelgarn, B. R., James, M. T., Klarenbach, S. W., Lewanczuk, R., Manns, B. J., Ronksley, P., Sargious, P., Straus, S., & Quan, H. (2015). Methods for identifying 30 chronic conditions: Application to administrative data. BMC Medical Informatics and Decision Making, 15(1). https://doi.org/10.1186/s12911-015-0155-5

Travers, J., Romero-Ortuno, R., Bailey, J., & Cooney, M.-T. (2019). Delaying and reversing frailty: A systematic review of primary care interventions. British Journal of General Practice, 69(678), e61–e69. https://doi.org/10.3399/bjgp18X700241

Turbow, S., Hollberg, J. R., & Ali, M. K. (2021). Electronic health record interoperability: How did we get here and how do we move forward? JAMA Health Forum, 2(3), e210253. https://doi.org/10.1001/jamahealthforum.2021.0253

U.S. Census Bureau. (2022). Nation's urban and rural populations shift following 2020 census (Press Release CB22-CN.25). https://www.census.gov/newsroom/press-releases/2022/urban-rural-populations.html

US Census Bureau. (2023, September 26). Urban and Rural. Census.Gov. https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural.html

U.S. Census Bureau. (2023, October 31). 2023 national population projections tables: Main series. Census.Gov. https://www.census.gov/data/tables/2023/demo/popproj/2023-summary-tables.html

Walsh, B., Fogg, C., Harris, S., Roderick, P., de Lusignan, S., England, T., Clegg, A., Brailsford, S., & Fraser, S. D. S. (2023). Frailty transitions and prevalence in an ageing population: Longitudinal analysis of primary care data from an open cohort of adults aged 50 and over in England, 2006–2017. Age and Ageing, 52(5), afad058. https://doi.org/10.1093/ageing/afad058

Wenger, N. S., Sanz Vidorreta, F. J., Dudley, M. T., Walling, A. M., & Hogarth, M. (2024). Consequences of a Health System Not Knowing Which Patients Are Deceased. JAMA Internal Medicine, 184(2), 213–214. https://doi.org/10.1001/jamainternmed.2023.6428

Wolfe, M. K., McDonald, N. C., & Holmes, G. M. (2020). Transportation Barriers to Health Care in the United States: Findings from the National Health Interview Survey, 1997–2017. American Journal of Public Health, 110(6), 815–822. https://doi.org/10.2105/AJPH.2020.305579

Xu, R., Li, Q., Guo, F., Zhao, M., & Zhang, L. (2021). Prevalence and risk factors of frailty among people in rural areas: A systematic review and meta-analysis. BMJ Open, 11(4), e043494. https://doi.org/10.1136/bmjopen-2020-043494

Yu, P., Song, X., Shi, J., Mitnitski, A., Tang, Z., Fang, X., & Rockwood, K. (2012). Frailty and survival of older Chinese adults in urban and rural areas: Results from the Beijing Longitudinal Study of Aging. Archives of Gerontology and Geriatrics, 54(1), 3–8. https://doi.org/10.1016/j.archger.2011.04.020

Zhang, X., Warner, M. E., & Wethington, E. (2020). Can Age-Friendly Planning Promote Equity in Community Health Across the Rural-Urban Divide in the US? International Journal of Environmental Research and Public Health, 17(4), Article 4. https://doi.org/10.3390/ijerph17041275

Table 4.1: Baseline characteristics at the time of cohort entry

	Overall	Urban	Rural	P-value
N	124,774	74,191	50,583	
Years of follow up, n (%)				<0.001
≤1	22,686 (18.2)	12,729 (17.2)	9,957 (19.7)	
>1 to 2	4,013 (3.2)	2,393 (3.2)	1,620 (3.2)	
>2 to 3	10,691 (8.6)	6,290 (8.5)	4,401 (8.7)	
>3 to 4	87,384 (70.0)	52,779 (71.1)	34,605 (68.4)	
Baseline state, n (%)				<0.001
Fit	55,535 (44.5)	32,246 (43.5)	23,289 (46.0)	
Pre-frail	54,146 (43.4)	32,369 (43.6)	21,777 (43.1)	
Frail	15,093 (12.1)	9,576 (12.9)	5,517 (10.9)	
Age years, median [IQR]	68.6 [62.1, 75.8]	68.7 [62.1, 76.1]	68.6 [62.2, 75.5]	<0.001
Age years, n (%)				<0.001
55-64	40,290 (32.3)	23,987 (32.3)	16,303 (32.2)	
65-74	46,579 (37.3)	27,197 (36.7)	19,382 (38.3)	
75+	37,905 (30.4)	23,007 (31.0)	14,898 (29.5)	
Sex, n (%)				<0.001
Female	71,180 (57.0)	43,616 (58.8)	27,564 (54.5)	
Male	53,594 (43.0)	30,575 (41.2)	23,019 (45.5)	
Race/Ethnicity, n (%)				<0.001
Black non-Hispanic/Latinx	15854 (12.7)	14139 (19.1)	1715 (3.4)	
Hispanic/Latinx	2313 (1.9)	1863 (2.5)	450 (0.9)	
Other[a] non-Hispanic/Latinx	2392 (1.9)	1803 (2.4)	589 (1.2)	
White non-Hispanic/Latinx	104,199 (83.5)	56,379 (76.0)	47,820 (94.5)	
Unknown	16 (0.0)	7 (0.0)	9 (0.0)	
Body mass index, median [IQR]	29.0 [25.4, 33.4]	28.8 [25.2, 33.3]	29.2 [25.7, 33.5]	<0.001
ADI, median [IQR]	70 [54, 81]	67 [47, 81]	72 [60, 80]	0.5
Deprivation, n (%)				<0.001
High (ADI>85)	19,118 (15.3)	13,266 (17.9)	5,852 (11.6)	
Mid/low	10,4979 (84.1)	60,320 (81.3)	44,659 (88.3)	
Missing	677 (0.5)	605 (0.8)	72 (0.1)	
Disadvantaged populations, n (%)				<0.001
High concentration ($ICE_{race} < 0$)	13,125 (10.5)	12,857 (17.3)	268 (0.5)	

Table 4.2: Baseline characteristics at the time of cohort entry (continued)

Mid/low concentration	111,649 (89.5)	61,334 (82.7)	50,315 (99.5)	
Anxiety, n (%)	25,426 (20.4)	15,223 (20.5)	10,203 (20.2)	0.136
Alcohol misuse, n (%)	2,813 (2.3)	1,902 (2.6)	911 (1.8)	<0.001
Smoking status, n (%)				0.007
Never	63,186 (50.6)	37,807 (51.0)	25,379 (50.2)	
Former or Current	61,588 (49.4)	36,384 (49.0)	25,204 (49.8)	
CCI, median [IQR]	1 [0, 3]	1 [0, 3]	1 [0, 3]	0.103
CVD, n (%)	13,688 (11.0)	8,378 (11.3)	5,310 (10.5)	<0.001
CHF, n (%)	10,563 (8.5)	6,446 (8.7)	4117 (8.1)	0.001
COPD, n (%)	29,051 (23.3)	17,190 (23.2)	11,861 (23.4)	0.256
Diabetes, n (%)	32,555 (26.1)	19,559 (26.4)	12,996 (25.7)	0.008
Malignancy, n (%)[b]	19,730 (15.8)	11,356 (15.3)	8,374 (16.6)	<0.001
Encounter count, prior year, median [IQR]	27 [13, 50]	29 [14, 54]	24 [12, 45]	<0.001
Outpatient visits, prior year, n (%)				<0.001
0 to 2	48,568 (38.9)	27,872 (37.6)	20,696 (40.9)	
3 to 5	40,992 (32.9)	23,979 (32.3)	17,013 (33.6)	
>5	35,214 (28.2)	22,340 (30.1)	12,874 (25.5)	

Note. Chi-square test for categorical variables and a Mann-Whiney two-sample test for non-normally distributed numeric variables. Abbreviations are as follows: Charlson comorbidity index (CCI), cerebrovascular disease (CVD), congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), index of concentration at the extremes (ICE).

[a]Other is inclusive of categories in the EMR labeled as American Indian or Alasa Native, Asian, multiracial, Native Hawaiian or Other Pacific Islander, and Other (not further specified).

[b]Excludes malignant neoplasm of skin.

Table 4.3: Prevalence of frailty states within cohort across time by Urban/Rural status at time of observations

Year	2018	2019	2020	2021	2022
Urban					
Total n	74,191	66,744	59,121	52,766	47,328
Fit, n (%)	32,246 (43.5%)	26,291 (39.4%)	22,162 (37.5%)	18,864 (35.8%)	15,594 (32.9%)
Pre-frail, n (%)	32,369 (43.6%)	30,519 (45.7%)	27,220 (46.0%)	24615 (46.6%)	22,799 (48.2%)
Frail, n (%)	9,576 (12.9%)	9,934 (14.9%)	9,739 (16.5%)	9,287 (17.6%)	8,935 (18.9%)
Rural					
Total n	50,583	44,887	38,937	34,605	30,938
Fit, n (%)	23,289 (46%)	19,135 (42.6%)	15,811 (40.6%)	13,377 (38.7%)	10,937 (35.4%)
Pre-frail, n (%)	21,777 (43.1%)	20,247 (45.1%)	17,892 (46.0%)	16,092 (46.5%)	15,022 (48.6%)
Frail, n (%)	55,17 (10.9%)	5,505 (12.3%)	5,234 (13.4%)	51,36 (14.8%)	4,979 (16.1%)

Note. Urban and rural residence status is time-varying.

Table 4.4: Estimated probabilities of state transitions over a one-year period from a multistate model stratified by urban-rural status

From state	To state	Urban probability (95% CI)	Rural probability (95% CI)
Fit	Fit	0.693 (0.690, 0.695)	0.695 (0.691, 0.698)
	Pre-frail	0.157 (0.154, 0.159)	0.144 (0.142, 0.147)
	Frail	0.010 (0.010, 0.010)	0.008 (0.008, 0.008)
	Death	0.019 (0.018, 0.020)	0.020 (0.019, 0.021)
	Missing	0.122 (0.120, 0.123)	0.133 (0.130, 0.135)
Pre-frail	Fit	0.117 (0.115, 0.119)	0.120 (0.117, 0.122)
	Pre-frail	0.716 (0.714, 0.719)	0.717 (0.715, 0.721)
	Frail	0.089 (0.087, 0.090)	0.078 (0.076, 0.080)
	Death	0.036 (0.035, 0.037)	0.039 (0.038, 0.040)
	Missing	0.042 (0.041, 0.044)	0.046 (0.044, 0.047)
Frail	Fit	0.015 (0.015, 0.016)	0.017 (0.016, 0.017)
	Pre-frail	0.185 (0.181, 0.188)	0.197 (0.192, 0.202)
	Frail	0.689 (0.684, 0.693)	0.664 (0.657, 0.670)
	Death	0.095 (0.092, 0.097)	0.101 (0.098, 0.106)
	Missing	0.017 (0.015, 0.018)	0.021 (0.019, 0.023)

Table 4.5: Associations between covariates and transition intensities in a multistate model by urban-rural residence

	Unadjusted		Adjusted		
	Urban	Rural	Urban	Rural	Additional rural association
Improvement					
Pre-frail to fit					
Age 65-74	**0.84 (0.77, 0.91)**	**0.84 (0.80, 0.89)**	**0.81 (0.75, 0.88)**	**0.83 (0.79, 0.87)**	1.02 (0.96, 1.09)
Age 75+	**0.69 (0.63, 0.75)**	**0.72 (0.68, 0.76)**	**0.64 (0.59, 0.70)**	**0.69 (0.65, 0.73)**	1.07 (1.00, 1.15)
Male	1.02 (0.96, 1.10)	0.96 (0.92, 1.00)	1.06 (0.98, 1.13)	1.00 (0.96, 1.04)	0.95 (0.89, 1.00)
Anxiety	**0.90 (0.82, 0.98)**	**0.93 (0.88, 0.98)**	**0.88 (0.81, 0.96)**	**0.90 (0.85, 0.95)**	1.02 (0.95, 1.09)
Alcohol misuse	0.92 (0.70, 1.21)	0.88 (0.74, 1.05)	0.94 (0.72, 1.25)	0.88 (0.74, 1.05)	0.93 (0.75, 1.15)
Smoking	**0.78 (0.73, 0.84)**	**0.80 (0.76, 0.83)**	**0.77 (0.71, 0.82)**	**0.78 (0.75, 0.82)**	1.02 (0.97, 1.08)
High deprivation	**0.87 (0.78, 0.97)**	**0.86 (0.80, 0.92)**	**0.88 (0.79, 0.99)**	**0.85 (0.79, 0.91)**	0.96 (0.88, 1.04)
Concentrated disadvantage	0.91 (0.61, 1.36)	**1.52 (1.15, 2.01)**	0.94 (0.64, 1.40)	**1.49 (1.13, 1.97)**	**1.58 (1.19, 2.10)**
Frail to pre-frail					
Age 65-74	0.89 (0.78, 1.02)	**0.86 (0.79, 0.93)**	**0.87 (0.76, 1.00)**	**0.84 (0.77, 0.91)**	0.97 (0.87, 1.07)
Age 75+	**0.73 (0.64, 0.83)**	**0.74 (0.68, 0.80)**	**0.68 (0.60, 0.78)**	**0.71 (0.66, 0.77)**	1.05 (0.94, 1.16)
Male	0.96 (0.87, 1.06)	1.03 (0.97, 1.10)	0.95 (0.86, 1.06)	**1.07 (1.00, 1.14)**	**1.12 (1.03, 1.22)**
Anxiety	**0.88 (0.79, 0.98)**	0.98 (0.92, 1.05)	**0.84 (0.75, 0.93)**	0.96 (0.90, 1.03)	**1.15 (1.05, 1.25)**
Alcohol misuse	0.99 (0.73, 1.33)	0.99 (0.82, 1.20)	0.96 (0.71, 1.30)	0.93 (0.77, 1.13)	0.97 (0.77, 1.23)
Smoking	**0.90 (0.82, 1.00)**	**0.91 (0.86, 0.97)**	**0.88 (0.79, 0.97)**	**0.87 (0.82, 0.92)**	0.99 (0.91, 1.07)
High deprivation	0.97 (0.85, 1.11)	1.06 (0.97, 1.16)	0.95 (0.83, 1.10)	1.05 (0.96, 1.15)	1.10 (0.99, 1.23)
Concentrated disadvantage	0.97 (0.46, 2.06)	1.09 (0.64, 1.86)	0.94 (0.44, 2.03)	1.05 (0.61, 1.80)	1.11 (0.64, 1.92)
Progression					
Fit to pre-frail					
Age 65-74	**1.23 (1.14, 1.33)**	**1.20 (1.15, 1.26)**	**1.25 (1.16, 1.35)**	**1.23 (1.18, 1.29)**	0.98 (0.93, 1.04)
Age 75+	**1.50 (1.38, 1.63)**	**1.39 (1.32, 1.46)**	**1.53 (1.41, 1.66)**	**1.43 (1.36, 1.50)**	**0.93 (0.88, 1.00)**
Male	0.96 (0.91, 1.03)	1.01 (0.97, 1.05)	0.95 (0.89, 1.01)	0.99 (0.95, 1.03)	1.04 (0.99, 1.10)
Anxiety	**1.31 (1.21, 1.43)**	**1.42 (1.35, 1.49)**	**1.34 (1.23, 1.46)**	**1.46 (1.39, 1.54)**	**1.09 (1.02, 1.17)**
Alcohol misuse	**1.62 (1.23, 2.13)**	**1.52 (1.28, 1.81)**	**1.45 (1.10, 1.92)**	**1.38 (1.16, 1.64)**	0.95 (0.77, 1.17)
Smoking	**1.35 (1.26, 1.43)**	**1.29 (1.24, 1.34)**	**1.30 (1.22, 1.39)**	**1.28 (1.23, 1.33)**	0.98 (0.93, 1.03)
High deprivation	**1.27 (1.16, 1.40)**	**1.08 (1.02, 1.14)**	**1.14 (1.04, 1.26)**	**1.08 (1.01, 1.14)**	0.94 (0.87, 1.02)
Concentrated disadvantage	1.28 (0.86, 1.91)	0.88 (0.67, 1.17)	1.20 (0.80, 1.81)	0.80 (0.60, 1.07)	**0.67 (0.50, 0.89)**
Pre-frail to frail					
Age 65-74	**1.25 (1.12, 1.41)**	**1.26 (1.17, 1.35)**	**1.32 (1.17, 1.48)**	**1.31 (1.22, 1.41)**	1.00 (0.91, 1.09)
Age 75+	**1.91 (1.71, 2.14)**	**1.91 (1.78, 2.05)**	**2.08 (1.86, 2.33)**	**2.06 (1.92, 2.21)**	0.99 (0.91, 1.08)
Male	**0.90 (0.83, 0.98)**	0.95 (0.91, 1.00)	**0.89 (0.82, 0.97)**	**0.92 (0.87, 0.96)**	1.03 (0.96, 1.10)
Anxiety	**1.29 (1.17, 1.41)**	**1.28 (1.21, 1.35)**	**1.33 (1.21, 1.46)**	**1.35 (1.27, 1.43)**	1.01 (0.94, 1.09)
Alcohol misuse	1.23 (0.95, 1.59)	**1.38 (1.17, 1.63)**	1.24 (0.96, 1.61)	**1.44 (1.22, 1.69)**	1.15 (0.95, 1.41)
Smoking	**1.28 (1.18, 1.39)**	**1.33 (1.26, 1.40)**	**1.32 (1.22, 1.44)**	**1.40 (1.33, 1.47)**	1.06 (0.99, 1.13)
High deprivation	**1.19 (1.06, 1.34)**	1.03 (0.95, 1.11)	1.12 (1.00, 1.27)	1.04 (0.96, 1.12)	0.92 (0.84, 1.01)
Concentrated disadvantage	1.18 (0.61, 2.30)	0.68 (0.43, 1.09)	1.19 (0.63, 2.25)	0.78 (0.50, 1.23)	0.66 (0.42, 1.04)

Table 4.6: Associations between covariates and transition intensities in a multistate model by urban-rural residence (continued)

Death Transitions					
Fit to death					
Age 65-74	**1.52 (1.10, 2.10)**	**1.82 (1.50, 2.20)**	**1.56 (1.13, 2.14)**	**1.85 (1.53, 2.24)**	1.19 (0.92, 1.54)
Age 75+	**6.27 (4.67, 8.41)**	**6.02 (5.03, 7.19)**	**6.28 (4.68, 8.43)**	**6.05 (5.06, 7.23)**	0.96 (0.76, 1.22)
Male	**1.65 (1.35, 2.00)**	**1.43 (1.27, 1.61)**	**1.47 (1.20, 1.80)**	**1.25 (1.10, 1.41)**	0.85 (0.72, 1.00)
Anxiety	0.93 (0.69, 1.25)	1.07 (0.90, 1.27)	1.14 (0.85, 1.53)	**1.36 (1.14, 1.62)**	1.19 (0.94, 1.51)
Alcohol misuse	**2.83 (1.24, 6.45)**	1.43 (0.83, 2.47)	**2.47 (1.09, 5.56)**	1.39 (0.81, 2.36)	0.56 (0.30, 1.04)
Smoking	**2.29 (1.88, 2.78)**	**1.99 (1.77, 2.24)**	**1.90 (1.55, 2.33)**	**1.82 (1.61, 2.05)**	0.95 (0.81, 1.12)
High deprivation	**1.60 (1.20, 2.12)**	1.16 (0.97, 1.39)	**1.53 (1.14, 2.06)**	1.09 (0.92, 1.31)	**0.71 (0.57, 0.90)**
Concentrated disadvantage	1.22 (0.57, 2.60)	**2.11 (1.24, 3.57)**	1.03 (0.48, 2.18)	**1.82 (1.08, 3.07)**	**1.78 (1.03, 3.07)**
Pre-frail to death					
Age 65-74	**1.35 (1.08, 1.69)**	**1.38 (1.21, 1.58)**	**1.41 (1.13, 1.77)**	**1.41 (1.24, 1.62)**	1.00 (0.83, 1.20)
Age 75+	**3.71 (3.02, 4.57)**	**3.29 (2.91, 3.72)**	**4.09 (3.32, 5.05)**	**3.45 (3.04, 3.91)**	**0.84 (0.71, 1.00)**
Male	**1.49 (1.30, 1.70)**	**1.41 (1.30, 1.53)**	**1.42 (1.23, 1.64)**	**1.28 (1.18, 1.40)**	0.90 (0.81, 1.01)
Anxiety	**0.86 (0.72, 1.02)**	**0.80 (0.72, 0.89)**	1.01 (0.84, 1.22)	0.96 (0.86, 1.08)	0.95 (0.82, 1.10)
Alcohol misuse	**1.72 (1.18, 2.51)**	**1.68 (1.32, 2.13)**	**1.85 (1.27, 2.71)**	**1.93 (1.52, 2.44)**	1.04 (0.77, 1.40)
Smoking	**1.31 (1.14, 1.50)**	**1.41 (1.29, 1.53)**	**1.27 (1.10, 1.47)**	**1.39 (1.27, 1.51)**	1.09 (0.97, 1.23)
High deprivation	1.21 (1.00, 1.47)	1.01 (0.89, 1.14)	**1.23 (1.01, 1.51)**	1.01 (0.89, 1.14)	**0.82 (0.70, 0.96)**
Concentrated disadvantage	1.11 (0.49, 2.52)	1.21 (0.68, 2.15)	1.15 (0.50, 2.65)	1.27 (0.71, 2.29)	1.11 (0.61, 2.01)
Frail to death					
Age 65-74	1.19 (0.91, 1.56)	**1.20 (1.02, 1.41)**	1.21 (0.93, 1.58)	**1.20 (1.02, 1.42)**	0.99 (0.80, 1.23)
Age 75+	**2.43 (1.91, 3.09)**	**2.45 (2.11, 2.84)**	**2.53 (1.98, 3.22)**	**2.44 (2.10, 2.84)**	0.97 (0.80, 1.17)
Male	**1.45 (1.26, 1.66)**	**1.40 (1.29, 1.53)**	**1.42 (1.23, 1.64)**	**1.36 (1.24, 1.48)**	0.95 (0.85, 1.07)
Anxiety	**0.80 (0.69, 0.94)**	**0.76 (0.69, 0.84)**	0.94 (0.80, 1.10)	**0.89 (0.80, 0.98)**	0.94 (0.83, 1.07)
Alcohol misuse	1.19 (0.82, 1.74)	1.19 (0.93, 1.51)	1.37 (0.93, 2.01)	**1.33 (1.04, 1.70)**	0.97 (0.73, 1.31)
Smoking	1.04 (0.90, 1.20)	1.02 (0.94, 1.11)	1.04 (0.90, 1.21)	1.01 (0.92, 1.11)	0.97 (0.86, 1.08)
High deprivation	0.99 (0.82, 1.19)	1.12 (0.99, 1.27)	1.10 (0.90, 1.33)	**1.14 (1.01, 1.29)**	1.04 (0.89, 1.21)
Concentrated disadvantage	0.94 (0.38, 2.28)	1.46 (0.78, 2.74)	1.03 (0.43, 2.44)	1.57 (0.86, 2.89)	1.53 (0.83, 2.83)

Note. The additional rural association indicates the estimate for the interaction term. HR indicates hazard ratio and CI indicates confidence interval. HRs with confidence intervals indicating significant results are bolded. Reference groups for subset of independent variables: Age (55-64), Sex-Male (Female), High deprivation (mid/low deprivation), Concentrated disadvantage (mid to low concentrated disadvantage).

Table 4.7: Estimated probabilities of state transitions over a one-year period from a multistate model stratified by urban-rural status with a similar number of observations for each

From state	To state	Urban probability (95% CI)	Rural probability (95% CI)
Fit	Fit	0.691 (0.688, 0.695)	0.695 (0.692, 0.698)
	Pre-frail	0.158 (0.156, 0.161)	0.144 (0.142, 0.147)
	Frail	0.010 (0.010, 0.010)	0.008 (0.008, 0.008)
	Death	0.019 (0.018, 0.020)	0.020 (0.019, 0.021)
	Missing	0.121 (0.119, 0.124)	0.133 (0.131, 0.135)
Pre-frail	Fit	0.118 (0.116, 0.120)	0.120 (0.117, 0.122
	Pre-frail	0.716 (0.712, 0.719)	0.718 (0.714, 0.721)
	Frail	0.089 (0.087, 0.091)	0.078 (0.076, 0.080)
	Death	0.035 (0.034, 0.036)	0.039 (0.038, 0.040)
	Missing	0.042 (0.041, 0.044)	0.046 (0.044, 0.047)
Frail	Fit	0.015 (0.015, 0.016)	0.017 (0.016, 0.017)
	Pre-frail	0.183 (0.179, 0.188)	0.197 (0.192, 0.202)
	Frail	0.690 (0.685, 0.696)	0.664 (0.658, 0.670)
	Death	0.094 (0.091, 0.098)	0.101 (0.097, 0.105)
	Missing	0.017 (0.015, 0.019)	0.021 (0.019, 0.023)

Table 4.8: Adjusted associations between covariates and transition intensities in a multistate model by urban-rural residence with similar number of observations for each group

	Urban	Rural	Additional rural association
Improvement			
Pre-frail to fit			
Age 65-74	**0.79 (0.73, 0.87)**	**0.83 (0.79, 0.87)**	1.04 (0.97, 1.12)
Age 75+	**0.64 (0.58, 0.70)**	**0.69 (0.65, 0.73)**	1.08 (1.00, 1.17)
Male	1.07 (0.99, 1.15)	1.00 (0.96, 1.04)	**0.93 (0.88, 0.99)**
Anxiety	**0.89 (0.81, 0.98)**	**0.90 (0.85, 0.95)**	1.00 (0.93, 1.08)
Alcohol misuse	0.93 (0.70, 1.24)	0.88 (0.74, 1.05)	0.95 (0.75, 1.19)
Smoking	**0.76 (0.71, 0.82)**	**0.78 (0.75, 0.82)**	1.02 (0.96, 1.09)
High deprivation	0.90 (0.81, 1.01)	**0.85 (0.79, 0.91)**	0.94 (0.86, 1.03)
Concentrated disadvantage	0.94 (0.63, 1.40)	**1.49 (1.13, 1.97)**	**1.59 (1.19, 2.11)**
Frail to pre-frail			
Age 65-74	**0.86 (0.75, 1.00)**	**0.84 (0.77, 0.91)**	0.97 (0.87, 1.09)
Age 75+	**0.69 (0.60, 0.79)**	**0.71 (0.66, 0.77)**	1.04 (0.93, 1.17)
Male	0.94 (0.85, 1.05)	**1.07 (1.00, 1.14)**	**1.13 (1.04, 1.24)**
Anxiety	**0.83 (0.74, 0.93)**	0.96 (0.90, 1.03)	**1.16 (1.06, 1.27)**
Alcohol misuse	1.04 (0.76, 1.42)	0.94 (0.77, 1.14)	0.90 (0.70, 1.15)
Smoking	**0.88 (0.79, 0.98)**	**0.87 (0.82, 0.92)**	0.99 (0.90, 1.07)
High deprivation	0.93 (0.80, 1.08)	1.05 (0.96, 1.15)	**1.13 (1.01, 1.27)**
Concentrated disadvantage	0.96 (0.44, 2.07)	1.04 (0.61, 1.79)	1.09 (0.63, 1.88)
Progression			
Fit to pre-frail			
Age 65-74	**1.22 (1.13, 1.32)**	**1.23 (1.18, 1.29)**	1.01 (0.95, 1.08)
Age 75+	**1.49 (1.36, 1.62)**	**1.43 (1.36, 1.50)**	0.96 (0.90, 1.03)
Male	0.95 (0.89, 1.02)	0.99 (0.95, 1.03)	1.04 (0.98, 1.09)
Anxiety	**1.34 (1.23, 1.47)**	**1.46 (1.39, 1.54)**	**1.09 (1.01, 1.17)**
Alcohol misuse	**1.35 (1.01, 1.81)**	**1.38 (1.15, 1.64)**	1.02 (0.81, 1.28)
Smoking	**1.29 (1.21, 1.38)**	**1.28 (1.23, 1.33)**	0.99 (0.93, 1.04)
High deprivation	**1.13 (1.02, 1.26)**	**1.08 (1.01, 1.14)**	0.95 (0.87, 1.03)
Concentrated disadvantage	1.21 (0.81, 1.83)	0.81 (0.61, 1.08)	**0.66 (0.50, 0.89)**
Pre-frail to frail			
Age 65-74	**1.32 (1.17, 1.49)**	**1.31 (1.22, 1.41)**	0.99 (0.90, 1.10)
Age 75+	**2.08 (1.85, 2.35)**	**2.06 (1.92, 2.21)**	0.99 (0.90, 1.09)
Male	**0.87 (0.80, 0.95)**	**0.91 (0.87, 0.96)**	1.05 (0.98, 1.13)
Anxiety	**1.27 (1.15, 1.41)**	**1.35 (1.27, 1.43)**	1.06 (0.98, 1.15)
Alcohol misuse	1.25 (0.95, 1.64)	**1.43 (1.21, 1.69)**	1.14 (0.92, 1.42)
Smoking	**1.31 (1.20, 1.43)**	**1.40 (1.33, 1.47)**	1.07 (0.99, 1.15)
High deprivation	**1.14 (1.00, 1.29)**	1.04 (0.96, 1.12)	0.91 (0.83, 1.01)
Concentrated disadvantage	1.19 (0.63, 2.25)	0.78 (0.50, 1.23)	0.66 (0.42, 1.04)
Death Transitions			
Fit to death			
Age 65-74	**1.63 (1.16, 2.29)**	**1.85 (1.53, 2.25)**	1.14 (0.86, 1.51)
Age 75+	**6.52 (4.77, 8.90)**	**6.05 (5.06, 7.23)**	0.93 (0.72, 1.20)
Male	**1.52 (1.23, 1.89)**	**1.25 (1.10, 1.41)**	**0.82 (0.69, 0.98)**
Anxiety	1.12 (0.82, 1.54)	**1.36 (1.14, 1.62)**	1.21 (0.93, 1.57)

Table 4.9: Adjusted associations between covariates and transition intensities in a multistate model by urban-rural residence with similar number of observations for each group (continued)

Alcohol misuse	**2.52 (1.09, 5.79)**	1.40 (0.82, 2.38)	0.55 (0.29, 1.05)
Smoking	**1.81 (1.46, 2.24)**	**1.82 (1.61, 2.05)**	1.00 (0.84, 1.20)
High deprivation	**1.55 (1.13, 2.11)**	1.10 (0.92, 1.31)	**0.71 (0.55, 0.91)**
Concentrated disadvantage	1.05 (0.49, 2.25)	**1.81 (1.07, 3.06)**	1.73 (0.99, 3.03)
Pre-frail to death			
Age 65-74	**1.40 (1.10, 1.79)**	**1.41 (1.24, 1.62)**	1.01 (0.83, 1.24)
Age 75+	**4.09 (3.27, 5.12)**	**3.45 (3.04, 3.91)**	0.84 (0.70, 1.02)
Male	**1.45 (1.24, 1.69)**	**1.28 (1.18, 1.40)**	0.89 (0.78, 1.00)
Anxiety	1.13 (0.93, 1.37)	0.96 (0.86, 1.08)	**0.85 (0.73, 1.00)**
Alcohol misuse	**1.79 (1.20, 2.68)**	**1.93 (1.52, 2.44)**	1.07 (0.78, 1.48)
Smoking	**1.25 (1.07, 1.46)**	**1.39 (1.27, 1.51)**	1.11 (0.98, 1.26)
High deprivation	1.22 (0.99, 1.51)	1.01 (0.89, 1.14)	**0.82 (0.69, 0.98)**
Concentrated disadvantage	1.18 (0.51, 2.74)	1.26 (0.70, 2.28)	1.07 (0.59, 1.96)
Frail to death			
Age 65-74	1.26 (0.95, 1.67)	**1.20 (1.02, 1.42)**	0.95 (0.76, 1.20)
Age 75+	**2.59 (2.00, 3.36)**	**2.45 (2.10, 2.84)**	0.94 (0.76, 1.16)
Male	**1.44 (1.23, 1.68)**	**1.36 (1.24, 1.48)**	0.94 (0.83, 1.07)
Anxiety	0.89 (0.75, 1.05)	**0.89 (0.80, 0.98)**	1.00 (0.87, 1.15)
Alcohol misuse	1.28 (0.86, 1.92)	**1.34 (1.05, 1.71)**	1.04 (0.76, 1.44)
Smoking	0.99 (0.85, 1.16)	1.01 (0.92, 1.11)	1.02 (0.90, 1.15)
High deprivation	1.10 (0.90, 1.36)	**1.14 (1.01, 1.29)**	1.03 (0.87, 1.21)
Concentrated disadvantage	1.06 (0.45, 2.53)	1.57 (0.86, 2.89)	1.48 (0.80, 2.74)

Note. The additional rural association indicates the estimate for the interaction term. HR indicates hazard ratio and CI indicates confidence interval. HRs with confidence intervals indicating significant results are bolded. Reference groups for subset of independent variables: Age (55-64), Sex-Male (Female), High deprivation (mid/low deprivation), Concentrated disadvantage (mid to low concentrated disadvantage).

Figure 4.1

Structure of multistate model

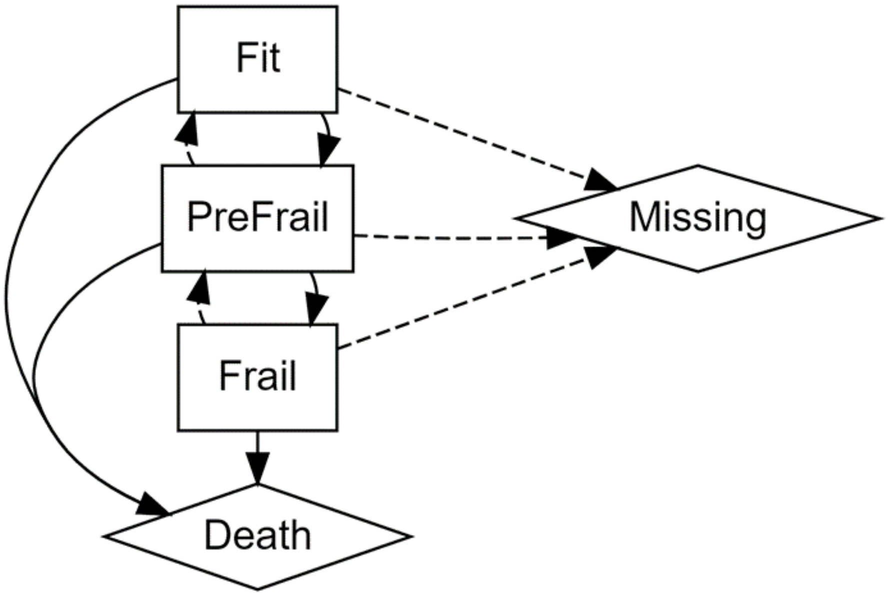


Figure 4.2

Prevalence of eFI states across time overall and by age and urban-rural status at baseline

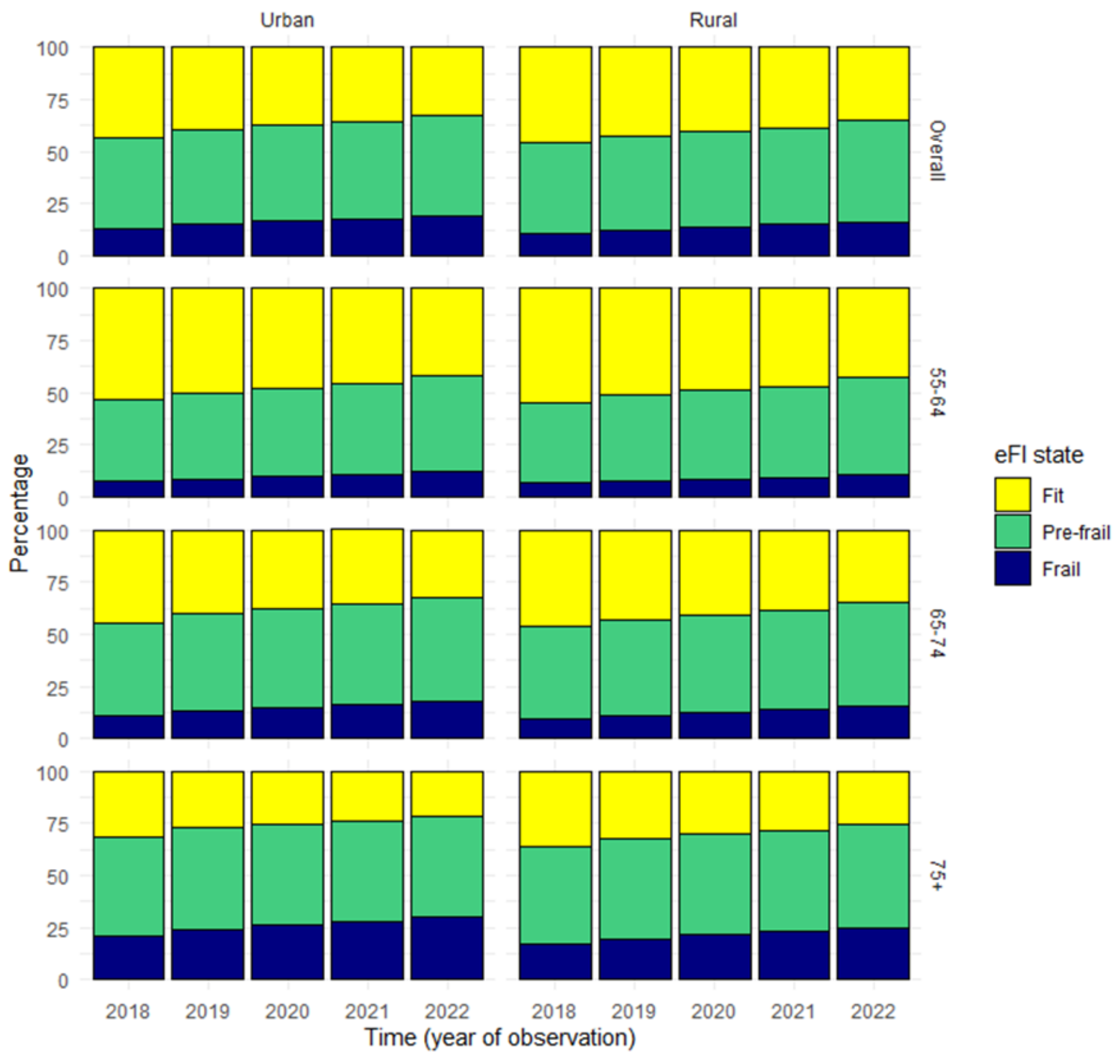


Figure 4.3

Forest plot of estimated probabilities of transitions for four years

CHAPTER 5: DISCUSSION

Summary of findings

This work was motivated by my previous collaboration on the development of an eFI at AHWFB (Pajewski et al. 2019), and this tool's potential utility in providing better healthcare for older adults. In the first manuscript, we considered if two factors that had been examined independently within narrowly defined cohorts might interact to increase the risk of emergency and inpatient care for older adults. Although the magnitude of frailty's association was larger than living in a disadvantaged area, we found that frailty and area disadvantage were jointly associated with acute care utilization. We also found that a large proportion of patients were able to be linked to an ADI, indicating that area-level measures are accessible to healthcare organizations and may be a scalable tool in detecting patients at higher risk for unmet functional, medical, and social needs that may benefit from more targeted interventions and further individual-level assessments of social need, which has been historically limited (Kreuter et al. 2021; Venzon, Le, and Kim 2019). The second and third were exploratory, and we sought to contribute to sparse literature leveraging longitudinal frailty measures to understand frailty development (Hoogendijk and Dent 2022). In the second manuscript, we characterized frailty prevalence, transitions, and factors associated with transitions with a focus on progression among patients 55 and older engaged with care at a large healthcare organization. We observed frailty transition patterns within a unique healthcare context were similar to those documented in international research (Romero-Ortuno et al. 2021; Walsh et al. 2023). While most individuals remained in a stable state, we noted transitions indicative of both progression and improvement. Older age, being female, having documented anxiety, alcohol misuse, a history of smoking, and living in areas of high deprivation or with high concentrations of disadvantaged populations were independently associated with a higher hazard of progressive transitions. The findings highlight the potential for healthcare and policy interventions to consider targeting individual and community-level factors in an effort to prevent or delay the onset of frailty. For the third manuscript, we found urban residents had a higher prevalence of frailty and higher probabilities of progressive transitions, while rural residents were more likely to go missing or die. Older age, female sex, anxiety, and previous or current smoking status were independently associated with higher hazard of progressing from a pre-frail to a frail state for both populations, while alcohol misuse was associated with a higher hazard of progression for rural residents only.

Implications

This work has implications for policy and future research. First, healthcare organizations have the opportunity to adapt their organizational policy to play a key role in supporting the health of older adults largely because this population is more engaged with healthcare (Ganguli et al. 2024). While screening for frailty among older adults is not mandated in the United States as it is in England (National Health Service England 2017), our findings that the eFI functions similarly and predicts risk for a host of adverse outcomes suggest that it may be useful for identifying vulnerable older adults in the United States as well. While federal policy change is certainly integral to addressing SDoH, there is also a call for healthcare organizations to consider SDoH in their healthcare delivery (Centers for Medicare and Medicaid 2022; Kreuter et al. 2021). For example, healthcare organizations can use risk-stratification tools in the electronic health record (EHR) to target vulnerable sub-populations of older adults, such as those who are frail and live in areas of deprivation, to improve care quality and potentially modify individual-level enabling factors to reduce preventable admission (Carter et al. 2018). This work informs potential community-level and individual-level interventions, population management strategies, and community partnerships, which are viable methods of enhancing health and care for older adults (Ahmed et al. 2022; Balaban et al. 2015; Coran, Schario, and Pronovost 2022; Preston et al. 2018; Schaaf et al. 2020). We must note that the implementation of these strategies should always be informed by equitable distribution of resources (Cary et al. 2023; Chin et al. 2023). We did not examine racial or ethnic disparities specifically, which is a critical area for future work. We did not examine individual-level race and ethnicity as a covariate in the second and third manuscript due to calls to examine the factors that underlie disparities and that can be changed (Duncan and Montoya-Williams 2024), and caution to not conflate social identities of race and ethnicity with genetic makeup that may indicate a predisposition for disease, but that is heterogeneous within these social groups (Umek and Fischer 2020). Although there is no one best practice to mitigate racial bias in clinical algorithms that could affect resource distribution, healthcare organizations might assess the proportions of sub-groups who are identified for an intervention as well as those who receive and benefit from that intervention and adjust their process accordingly to ensure equity (Cary et al. 2023; Chin et al. 2023).

These findings are exploratory and set the stage for more hypothesis-driven research. For instance, since frailty and area disadvantage are jointly associated with acute care utilization, future studies can specifically test interventions that address both elements simultaneously to see if they effectively reduce acute care utilization. This research also helps identify potential variables and relationships that may not have been considered previously. For example, in the third manuscript, the observation of different frailty transitions among urban and rural residents can generate hypotheses about the role of geographic and social environments in the development of frailty, which should be further explored.

Limitations

The work presented in this dissertation should be considered in the context of several limitations. A limitation of BMHSU is that the model lacks clarity in whether factors can be modelled as mediators or modifiers of other variables associated with healthcare use, which is common social ecology applications and explored in the first manuscript (von Lengerke, Gohl, and Babitsch 2014). However, we laid a foundation for exploring why individuals living in disadvantaged neighborhoods and with frailty may face compounded challenges. The lack of healthcare access and other resources can delay the routine management of chronic conditions, leading to acute crises that necessitate emergency care. Similarly, physical environment may exacerbate health issues, such as falls or injuries, among frail individuals in increase acute care utilization. Another limitation is that the second and third studies used data that were collected during the COVID-19 pandemic, threatening internal validity. We noted modest increases in time-varying rates of missingness at the beginning of the pandemic, but relatively stable rates of change across the observation period, although we cannot completed disentangle the effects of COVID-19.

We should note that the effective use of an eFI and health organization policies are subject to limitations in interoperability and data fragmentation, which must be improved (Federal Register 2020; Reisman 2017). Consequently, an individual in the dataset might appear fit simply due to the absence of certain data that are available at other organizations but not integrated into AHWFB's structured data. To mitigate this limitation, we have established a requirement for a minimum number of data elements to be present to calculate the eFI (Pajewski et al. 2019). While generalizability may be limited beyond AHWFB, it is important to consider that organizations are often reliant on their own data to inform algorithms and clinical decisions.

Our findings suggest value in considering the factors explored these studies in the creation of organizational policies despite the limitations of the United States' unique healthcare context. However, this may not be feasible for smaller healthcare organizations, and this work does not address the needs older adults without healthcare access.

Conclusion

This dissertation research focused on the exploration of how structured data from the electronic medical record might be leveraged to identify older adults with elevated risk of experiencing adverse events. The findings give insights to inform contextual level enabling factors, such as policies that involve population management and risk stratification for older adults and pave the way for more hypothesis-driven research exploring the development of frailty.

GENERAL REFERENCES

Ahmed, Sonia, Liana E. Chase, Janelle Wagnild, Nasima Akhter, Scarlett Sturridge, Andrew Clarke, Pari Chowdhary, et al. 2022. "Community Health Workers and Health Equity in Low- and Middle-Income Countries: Systematic Review and Recommendations for Policy and Practice." *International Journal for Equity in Health* 21(1): 49. doi:10.1186/s12939-021-01615-y.

Andersen, R. M., P. L. Davidson, and S. E. Baumeister. 2013. "Improving Access to Care in America: Individual and Contextual Indicators." In *Changing the U.S. Health Care System: Key Issues in Health Services Policy and Management*, ed. G. F. Kominski. San Francisco, California: Jossey-Bass, 33–69.

Andreescu, Carmen, and Soyoung Lee. 2020. "Anxiety Disorders in the Elderly." In *Anxiety Disorders*, Springer, Singapore, 561–76. doi:10.1007/978-981-32-9705-0_28.

Babitsch, Birgit, Daniela Gohl, and Thomas von Lengerke. 2012. "Re-Revisiting Andersen's Behavioral Model of Health Services Use: A Systematic Review of Studies from 1998-2011." *Psycho-Social Medicine* 9: Doc11. doi:10.3205/psm000089.

Balaban, Richard B., Alison A. Galbraith, Marguerite E. Burns, Catherine E. Vialle-Valentin, Marc R. Larochelle, and Dennis Ross-Degnan. 2015. "A Patient Navigator Intervention to Reduce Hospital Readmissions among High-Risk Safety-Net Patients: A Randomized Controlled Trial." *Journal of General Internal Medicine* 30(7): 907–15. doi:10.1007/s11606-015-3185-x.

Bandeen-Roche, Karen, Christopher L. Seplaki, Jin Huang, Brian Buta, Rita R. Kalyani, Ravi Varadhan, Qian-Li Xue, Jeremy D. Walston, and Judith D. Kasper. 2015. "Frailty in Older Adults: A Nationally Representative Profile in the United States." *The Journals of Gerontology: Series A* 70(11): 1427–34. doi:10.1093/gerona/glv133.

Breslow, Rosalind A., I-Jen P. Castle, Chiung M. Chen, and Barry I. Graubard. 2017. “Trends in Alcohol Consumption among Older Americans: National Health Interview Surveys, 1997–2014.” *Alcoholism, clinical and experimental research* 41(5): 976–86. doi:10.1111/acer.13365.

Carter, Nancy, Ruta K. Valaitis, Annie Lam, Janice Feather, Jennifer Nicholl, and Laura Cleghorn. 2018. “Navigation Delivery Models and Roles of Navigators in Primary Care: A Scoping Literature Review.” *BMC Health Services Research* 18: 1–13. doi:10.1186/s12913-018-2889-0.

Cary, Michael P., Anna Zink, Sijia Wei, Andrew Olson, Mengying Yan, Rashaud Senior, Sophia Bessias, et al. 2023. “Mitigating Racial and Ethnic Bias and Advancing Health Equity in Clinical Algorithms: A Scoping Review.” *Health Affairs* 42(10): 1359–68. doi:10.1377/hlthaff.2023.00553.

Chin, Marshall H., Nasim Afsar-Manesh, Arlene S. Bierman, Christine Chang, Caleb J. Colón-Rodríguez, Prashila Dullabh, Deborah Guadalupe Duran, et al. 2023. “Guiding Principles to Address the Impact of Algorithm Bias on Racial and Ethnic Disparities in Health and Health Care.” *JAMA Network Open* 6(12): e2345050. doi:10.1001/jamanetworkopen.2023.45050.

Clegg, Andrew, Chris Bates, John Young, Ronan Ryan, Linda Nichols, Elizabeth Ann Teale, Mohammed A. Mohammed, John Parry, and Tom Marshall. 2016. “Development and Validation of an Electronic Frailty Index Using Routine Primary Care Electronic Health Record Data.” *Age and Ageing* 45(3): 353–60. doi:10.1093/ageing/afw039.

Clegg, Andrew, John Young, Steve Iliffe, Marcel Olde Rikkert, and Kenneth Rockwood. 2013. “Frailty in Elderly People.” *Lancet* 381(9868): 752–62. doi:10.1016/S0140-6736(12)62167-9.

Coran, Justin J., Mark E. Schario, and Peter J. Pronovost. 2022. “Stratifying for Value: An Updated Population Health Risk Stratification Approach.” *Population Health Management* 25(1): 91–99. doi:10.1089/pop.2021.0096.

Demiris, George, Nancy A. Hodgson, Justine S. Sefcik, Jasmine L. Travers, Miranda Varrassee McPhillips, and Mary D. Naylor. 2020. “High Value Care for Older Adults with Complex Care Needs: Leveraging Nurses as Innovators.” *Nursing outlook* 68(1): 26–32. doi:10.1016/j.outlook.2019.06.019.

Duncan, Andrea F., and Diana Montoya-Williams. 2024. “Recommendations for Reporting Research About Racial Disparities in Medical and Scientific Journals.” *JAMA Pediatrics* 178(3): 221–24. doi:10.1001/jamapediatrics.2023.5718.

Federal Register. 2020. “21st Century Cures Act: Interoperability, Information Blocking, and the ONC Health IT Certification Program.” *Federal Register*. https://www.federalregister.gov/documents/2020/05/01/2020-07419/21st-century-cures-act-interoperability-information-blocking-and-the-onc-health-it-certification (April 17, 2022).

Ferri-Guerra, J., R. Aparicio-Ugarriza, D. Salguero, D. Baskaran, Y. N. Mohammed, H. Florez, and J. G. Ruiz. 2020. “The Association of Frailty with Hospitalizations and Mortality among Community Dwelling Older Adults with Diabetes.” *The Journal of Frailty & Aging* 9(2): 94–100. doi:10.14283/jfa.2019.31.

Ganguli, Ishani, Emma D. Chant, E. John Orav, Ateev Mehrotra, and Christine S. Ritchie. 2024. “Health Care Contact Days Among Older Adults in Traditional Medicare.” *Annals of Internal Medicine* 177(2): 125–33. doi:10.7326/M23-2331.

Gosselin, Patrick, Camille Castonguay, Marika Goyette, Rosemarie Lambert, Mallorie Brisson, Philippe Landreville, and Sébastien Grenier. 2022. “Anxiety among Older Adults during the COVID-19 Pandemic.” *Journal of Anxiety Disorders* 92: 102633. doi:10.1016/j.janxdis.2022.102633.

Han, Lu, Andrew Clegg, Tim Doran, and Lorna Fraser. 2019. “The Impact of Frailty on Healthcare Resource Use: A Longitudinal Analysis Using the Clinical Practice Research Datalink in England.” *Age and Ageing* 48(5): 665–71. doi:10.1093/ageing/afz088.

Hoogendijk, Emiel O., and Elsa Dent. 2022. “Trajectories, Transitions, and Trends in Frailty among Older Adults: A Review.” *Annals of Geriatric Medicine and Research* 26(4): 289–95. doi:10.4235/agmr.22.0148.

Hunt, Lauren J., Kenneth E. Covinsky, Irena Cenzer, Edie Espejo, W. John Boscardin, Heather Leutwyler, Alexandra K. Lee, and Janine Cataldo. 2023. “The Epidemiology of Smoking in Older Adults: A National Cohort Study.” *Journal of General Internal Medicine* 38(7): 1697–1704. doi:10.1007/s11606-022-07980-w.

Ilinca, Stefania, and Stefano Calciolari. 2015. “The Patterns of Health Care Utilization by Elderly Europeans: Frailty and Its Implications for Health Systems.” *Health Services Research* 50(1): 305–20. doi:10.1111/1475-6773.12211.

Kim, Dani J., M. Sofia Massa, Caroline M. Potter, Robert Clarke, and Derrick A. Bennett. 2022. “Systematic Review of the Utility of the Frailty Index and Frailty Phenotype to Predict

All-Cause Mortality in Older People." *Systematic Reviews* 11: 187. doi:10.1186/s13643-022-02052-w.

Kreuter, Matthew W., Tess Thompson, Amy McQueen, and Rachel Garg. 2021. "Addressing Social Needs in Health Care Settings: Evidence, Challenges, and Opportunities for Public Health." *Annual Review of Public Health* 42(1): 329–44. doi:10.1146/annurev-publhealth-090419-102204.

von Lengerke, Thomas, Daniela Gohl, and Birgit Babitsch. 2014. "Re-Revisiting the Behavioral Model of Health Care Utilization by Andersen: A Review on Theoretical Advances and Perspectives." In *Health Care Utilization in Germany: Theory, Methodology, and Results*, eds. Christian Janssen, Enno Swart, and Thomas von Lengerke. New York, NY: Springer New York, NY, 11–28. doi:10.1007/978-1-4614-9191-0_2.

Lenoir, Kristin M., Rajib Paul, Elena Wright, Deepak Palakshappa, Nicholas M. Pajewski, Amresh Hanchate, Jaime M. Hughes, et al. 2023. "The Association of Frailty and Neighborhood Disadvantage with Emergency Department Visits and Hospitalizations in Older Adults." *Journal of General Internal Medicine*. doi:10.1007/s11606-023-08503-x.

Lim, Arum, JiYeon Choi, Hyunju Ji, and Hyangkyu Lee. 2022. "Frailty Assessment Using Routine Clinical Data: An Integrative Review." *Archives of Gerontology and Geriatrics* 99: 104612. doi:10.1016/j.archger.2021.104612.

Muscedere, John, Melissa K. Andrew, Sean M. Bagshaw, Carole Estabrooks, David Hogan, Jayna Holroyd-Leduc, Susan Howlett, et al. 2016. "Screening for Frailty in Canada's Health Care System: A Time for Action." *Canadian Journal on Aging* 35(3): 281–97. doi:10.1017/S0714980816000301.

National Health Service England. 2017. "NHS England » Identifying Frailty." *Supporting routine frailty identification and frailty through the GP contract 2017/2018*. https://www.england.nhs.uk/ourwork/ltc-op-eolc/older-people/frailty/supporting-resources-general-practice/ (November 25, 2020).

Pajewski, Nicholas M, Kristin Lenoir, Brian J Wells, Jeff D Williamson, and Kathryn E Callahan. 2019. "Frailty Screening Using the Electronic Health Record within a Medicare Accountable Care Organization." *Journals of Gerontology* 74(11): 1771–77. doi:https://doi.org/10.1093/gerona/glz017.

Parker, Maria A., Andrea H. Weinberger, Emma M. Eggers, Erik S. Parker, and Andrea C. Villanti. 2022. "Trends in Rural and Urban Cigarette Smoking Quit Ratios in the US From 2010 to 2020." *JAMA Network Open* 5(8): e2225326. doi:10.1001/jamanetworkopen.2022.25326.

Preston, L, D Chambers, F Campbell, A Cantrell, J Turner, and E Goyder. 2018. "What Evidence Is There for the Identification and Management of Frail Older People in the Emergency Department? A Systematic Mapping Review." *Health Services and Delivery Research* 6(16): 1–168. doi:10.3310/hsdr06160.

Reisman, Miriam. 2017. "EHRs: The Challenge of Making Electronic Data Usable and Interoperable." *Pharmacy and Therapeutics* 42(9): 572–75.

Romero-Ortuno, Roman, Peter Hartley, Silvin P. Knight, Rose Anne Kenny, and Aisling M. O'Halloran. 2021. "Frailty Index Transitions over Eight Years Were Frequent in The Irish Longitudinal Study on Ageing." doi:10.12688/hrbopenres.13286.1.

Romero-Ortuno, Roman, and Rose Anne Kenny. 2012. "The Frailty Index in Europeans: Association with Age and Mortality." *Age and Ageing* 41(5): 684–89. doi:10.1093/ageing/afs051.

Rowe, John W., Terry Fulmer, and Linda Fried. 2016. "Preparing for Better Health and Health Care for an Aging Population." *JAMA* 316(16): 1643–44. doi:10.1001/jama.2016.12335.

Schaaf, Marta, Caitlin Warthin, Lynn Freedman, and Stephanie M. Topp. 2020. "The Community Health Worker as Service Extender, Cultural Broker and Social Change Agent: A Critical Interpretive Synthesis of Roles, Intent and Accountability." *BMJ Global Health* 5(6): e002296. doi:10.1136/bmjgh-2020-002296.

Travers, John, Roman Romero-Ortuno, Jade Bailey, and Marie-Therese Cooney. 2019. "Delaying and Reversing Frailty: A Systematic Review of Primary Care Interventions." *British Journal of General Practice* 69(678): e61–69. doi:10.3399/bjgp18X700241.

Umek, Wolfgang, and Barbara Fischer. 2020. "We Should Abandon 'Race' as a Biological Category in Biomedical Research." *Female Pelvic Medicine & Reconstructive Surgery* 26(12): 719–20. doi:10.1097/SPV.0000000000000979.

Venzon, Aldreen, Thuy Bich Le, and Katherine Kim. 2019. "Capturing Social Health Data in Electronic Systems: A Systematic Review." *CIN: Computers, Informatics, Nursing* 37(2): 90. doi:10.1097/CIN.0000000000000481.

Walsh, Bronagh, Carole Fogg, Scott Harris, Paul Roderick, Simon de Lusignan, Tracey England, Andrew Clegg, Sally Brailsford, and Simon D S Fraser. 2023. "Frailty Transitions and Prevalence in an Ageing Population: Longitudinal Analysis of Primary Care Data from an Open Cohort of Adults Aged 50 and over in England, 2006–2017." *Age and Ageing* 52(5): afad058. doi:10.1093/ageing/afad058.

APPENDIX

Ethical approval letters

WAKE FOREST UNIVERSITY
HEALTH SCIENCES

Office of Research
INSTITUTIONAL REVIEW BOARD

MEMORANDUM

To: Kristin Lenoir
Biostatistics and Data Science

From: Jeannie Sekits, Senior Protocol Analyst
Institutional Review Board

Date: 10/16/2023

Subject: Exempt Protocol: IRB00102411
Exploring the Role of the Electronic Frailty Index (eFI) in Identifying Vulnerable Older Adults in a Healthcare Setting

No protected health information will be used or disclosed in this research proposal; therefore the requirement for individual Authorization does not apply.

This research meets the criteria for a waiver of HIPAA authorization according to 45 CFR 164.512.

Exemption Category 4 - Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. null (Category null).

Note that only the Wake Forest University School of Medicine IRB can make the determination for its investigators that a research study is exempt. Investigators do not have the authority to make an independent determination that research involving human subjects is exempt. Each project requires a separate review and approval or exemption. The Board must be informed of any changes to this project, so that the Board can determine whether it continues to meet the requirements for exemption.

The Wake Forest School of Medicine IRB is duly constituted, has written procedures for initial and continuing review of clinical trials; prepares written minutes of convened meetings, and retains records pertaining to the review and approval process; all in compliance with requirements of FDA regulations 21 CFR Parts 50 and 56, HHS regulations 45 CFR 46, and International Conference on Harmonisation (ICH) E6, Good Clinical Practice (GCP), as applicable. WFSM IRB is registered with OHRP/FDA; our IRB registration numbers are IRB00000212, IRB00002432, IRB00002433, IRB00002434, IRB00008492, IRB00008493, IRB00008494, and IRB00008495.
WFSM IRB has been continually fully accredited by the Association for the Accreditation of Human Research Protection Programs (AAHRPP) since 2011.

Medical Center Boulevard, Winston-Salem, NC 27157-1023 (336) 716-4542 / fax (336) 716-4480

CHARLOTTE
DIVISION OF RESEARCH

To:	Kristin Lenoir University of North Carolina at Charlotte
From:	Office of Research Protections and Integrity
Approval Date:	22-Oct-2023
RE:	Notice of Determination of Exemption
Exemption Category:	4
Study #:	IRB-24-0315
Study Title:	Exploring the Role of the Electronic Frailty Index (eFI) in Identifying Vulnerable Older Adults in a Healthcare Setting

This submission has been reviewed by the Office of Research Protections and Integrity (ORPI) and was determined to meet the Exempt category cited above under 45 CFR 46.104(d). This determination has no expiration or end date and is not subject to an annual continuing review. However, you are required to obtain approval for all changes to any aspect of this study before they can be implemented and to comply with the Investigator Responsibilities detailed below.

Your approved consent forms (if applicable) and other documents are available online at Submission Page.

Investigator's Responsibilities:

1. Amendments must be submitted for review and the amendment approved before implementing the amendment. This includes changes to study procedures, study materials, personnel, etc.
2. Researchers must adhere to all site-specific requirements mandated by the study site (e.g., face mask, access requirements and/or restrictions, etc.).
3. Data security procedures must follow procedures as described in the protocol and in accordance with OneIT Guidelines for Data Handling.
4. Promptly notify the IRB office (uncc-irb@charlotte.edu) of any adverse events or unanticipated risks to participants or others.
5. Five years (5) following this approval/determination, you must complete the Admin-Check In form via Niner Research to provide a study status update.
6. Be aware that this study is included in the Post-Approval Monitoring program and may be selected for post-review monitoring at some point in the future.
7. Reply to the ORPI post-review monitoring and administrative check-ins that will be conducted periodically to update ORPI as to the status of the study.
8. Complete the Closure eform via Niner Research once the study is complete.

Permissions for Copyrighted Materials

SPRINGER NATURE LICENSE
TERMS AND CONDITIONS

Apr 26, 2024

This Agreement between Wake Forest University School of Medicine -- Kristin Lenoir ("You") and Springer Nature ("Springer Nature") consists of your license details and the terms and conditions provided by Springer Nature and Copyright Clearance Center.

License Number	5776551210001
License date	Apr 26, 2024
Licensed Content Publisher	Springer Nature
Licensed Content Publication	Journal of General Internal Medicine
Licensed Content Title	The Association of Frailty and Neighborhood Disadvantage with Emergency Department Visits and Hospitalizations in Older Adults
Licensed Content Author	Kristin M. Lenoir MPH et al
Licensed Content Date	Nov 6, 2023
Type of Use	Thesis/Dissertation
Requestor type	academic/university or research institute
Format	electronic
Portion	full article/chapter
Will you be translating?	no
Circulation/distribution	50000 or greater
Author of this Springer Nature content	yes
Title of new work	Exploring the Role of the Electronic Frailty Index (eFI in Identifying Vulnerable Older Adults in a Healthcare Setting
Institution name	University of North Carolina at Charlotte
Expected presentation date	Dec 2024
Order reference number	1
Requestor Location	Wake Forest University School of Medicine 1 Medical Center Blvd WINSTON SALEM, NC 27157 United States Attn: Wake Forest University School of Medicine