The Paradox of Resilience: Lower Mortality Among Unhoused Trauma Patients in the Pacific Northwest

Nina Mirabadi

A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Science

University of Washington

2025

Committee:

Ali Rowhani-Rahbar

Scott Brakenridge

Program Authorized to Offer Degree:

Epidemiology

University of Washington

Abstract

The Paradox of Resilience: Lower Mortality Among Unhoused Trauma Patients in the Pacific Northwest

Nina Mirabadi

Chair of the Supervisory Committee:

Ali Rowhani-Rahbar

Department of Epidemiology

There is a gap in knowledge in the role chronic stress plays in response to subsequent acute stressors, with equipoise as to whether chronic stress may be protective. To study the possibility that individuals who experience chronic stress may be more resilient to an acute stressor, we aim to measure the time-to-event differences between housed and unhoused trauma patients after an acute injury, with reduced time to recovery as a marker of resilience. We conducted a retrospective, observational cohort study of trauma patients at a single center (N=7,666) separated by housing status from 2016-2019. Cox proportional hazards modeling, competing risk, and zero-inflated negative binomial regression was used to assess in-hospital mortality, differences in time to ICU discharge, and outcome-free survival at 60 days by housing status, when adjusting for trauma-related covariates. Unhoused patients had a 34.5% lower hazard of all-cause in-hospital mortality compared to housed (HR 0.66, 95% CI: 0.44-0.98, p-value=0.04). There was no difference in the time to ICU discharge, number of days liberated from ventilation, nor number of days spent out of the ICU. However, unhoused trauma patients had longer hospital admissions. Unhoused trauma patients had significantly lower all-cause in-hospital mortality compared to housed trauma patients, despite having arrived in more critical condition.

Background:

Chronic stress, defined as maladaptation due to recurrent, persistent, or prolonged stress resulting in alterations in neuroendocrine patterns and inability to resolve to a state of homeostatic balance,[1,2,3] is increasingly recognized as a powerful determinant of health. The primary framework within the stress literature theorizes that chronic stress is the result of allostatic overload, whereby stressors result in an individual's inability to maintain a state of allostasis—a system of dynamic biological set-points that change parameters to maintain physiological stability in the face of stress—resulting in a dysregulated stress response.[3,4,5] Allostatic overload can arise from frequent stressors resulting in chronic stress, lack of adaptation to repeated stressors, inability to downregulate a stress response after the stressor is terminated, or insufficient allostatic response to a stressor.[4,5] While chronic over-activation of the physiological stress response via the sympathetic-adrenal-medullary (SAM) axis and/or hypothalamic-pituitary-adrenal (HPA) axis are initially adaptive, overtime the biological systems perpetually overcompensate which results in the organism being susceptible to stress-related diseases.[4,5,6,7]
The development of long-term poor health outcomes due to allostatic overload and chronic stress have been well documented. Several studies have shown increased risk of disease with increased allostatic load including: cardiovascular diseases such as coronary heart disease, ischemic heart disease, and peripheral heart disease;[8,9,10] type II diabetes;[11] early age at menarche;[12] neurologic disorders such as depressive symptoms after traumatic brain injury and seizures;[13,14] breast and ovarian cancer;[15] and other mental health disorders such as mood and anxiety disorders, PTSD, alcohol dependence, and schizophrenia.[16,17,18,19,20] Chronic stress has also been shown to affect specific biological systems including neurologic effects, immune suppression or blunting, and heightened cortisol levels.[5,6] Additionally, the study of Adverse Childhood Experiences (ACEs) has demonstrated an association between higher allostatic load early in life (ACEs≥4) and increased likelihood of developing chronic health conditions such as injury (higher rates of traumatic brain injuries, fractures, burns), mental health (depression, anxiety suicide, post-traumatic stress disorder), maternal health (unintended pregnancy, pregnancy complications, and fetal death), infectious disease, chronic disease (cancer, diabetes), risky behaviors (alcohol and drug abuse, condomless sex), and reduced opportunities (lower education, reduced income, and higher unemployment).[21,22,23]

While chronic stress is widely linked to adverse long-term health outcomes, there is a gap in knowledge in the role chronic stress plays in response to subsequent acute stressors. The ability of an individual to "bounce back" from an acute stressor is a marker of their resilience, defined as the ability of a system to return to baseline functioning (pre-stressor homeostasis) after a threatening, harmful, or challenging event.[24,25,26] According to the NIH Resilience Concept Model, ones' resilience to stress depends on the type, magnitude, and duration of the stressor resulting in variation in system responses.[27] This variation has been seen in some studies demonstrating that exposure to repeated stress that is manageable or of moderate adversity results in increased adaptive capacity to future acute stressors, termed stress inoculation.[28] Additionally, adaptive calibration model theorizes that individuals evolve to adapt to their environments, suggesting that chronic stress is a strategic calibration to adapt and survive to physiological stress, and may lead to them thriving better in a stressful environment than those who are not similarly stress challenged.[29,30] At this time, there is equipoise as to whether chronic stress may be protective to subsequent acute stressors given limited data.

To study the possibility that individuals who experience chronic stress may be more resilient to an acute stressor, we aim to measure the time-to-event differences between housed and unhoused trauma patients after an acute injury. Several studies within stress research have proposed theories regarding the conceptualization of resilience, but since there have been no general consensus to date,[26] we will use measures of adjusted all-cause in-hospital mortality, time to ICU discharge, 60-day ventilator free survival, 60-day ICU free survival, and 60-day hospital free survival as clinical proxies of resilience.

We chose to study unhoused individuals because they are a vulnerable population who face a multitude of psychosocial stressors resulting in chronic stress.[31] Previous work has shown that exposure to chronic stress in this population begets adverse health outcomes including mental health disorders, substance use, and chronic diseases such as diabetes, peripheral and cardiovascular disease, dementia, soft tissue infections, cancers, and respiratory diseases.[32,33] At the same time, it is known that unhoused individuals are at higher risk of acute stressors such as traumatic injury compared to their housed counterparts, largely due to increased victimization.[34] Prior studies have shown notable differences in injury patterns between the two groups, with the unhoused experiencing higher rates of assault, pedestrian-strike, and head injury.[35,36] Three recent papers have studied differences in clinical outcomes between housed and unhoused trauma patients using matched controls[37,38] or descriptive analysis[39]. Both Silver et al and Kovacs et al found that unhoused patients had longer hospital length of stay (LOS), but no difference in hospital mortality in the former, versus a 0.85 lower odds of in-hospital mortality in unhoused patients compared to housed in the latter, though this was not statistically significant. In all prior analyses, logistic regression was used to quantify the outcome differences; in contrast, we propose a time-to-event modeling approach that will allow us to assess acute resilience over the hospital course.

Thus, we hypothesize that unhoused patients will have greater resilience to acute injury, manifesting as lower in-hospital mortality and reduced time to recovery, compared to housed patients due to the potentially protective effects of chronic stress.

Methods:

Study Design:

We conducted a retrospective, observational cohort study using patient-level data from a single Level I trauma center within the WWAMI (Washington, Wyoming, Alaska, Montana, Idaho) region’s traumatically injured patient population from 2016-2019. The study used time-to-event analysis to compare critical care and hospital outcomes between unhoused and housed trauma patients while adjusting for sex, age, injury mechanism, injury severity score (ISS), and modified

Charleston Comorbidity Index (CCI). Patients were under observation from the time of traumatic injury until hospital discharge. Our study design allowed us to capture differences in all-cause in-hospital mortality, ICU time to discharge, 60-day ventilator-free survival time, 60-day ICU-free survival time, and 60-day hospital-free survival time between housed and unhoused trauma patients. This study was approved by the University of Washington institutional review board (IRB # STUDY00021959), with a waiver of informed consent.

Study Setting:

This study was conducted at Harborview Medical Center (HMC), which is a 413 bed designated, level 1 adult and pediatric trauma center in Seattle, Washington, USA. HMC is the public safety net hospital for King County, serving a population of 2.2 million people with an estimated 7000 trauma admissions yearly, and is partnered with the University of Washington-School of Medicine to serve the catchment area of the WWAMI region. All trauma patients who are injured within these 5 states, and require a level of care beyond what local-regional Level II and III trauma centers can provide, are transported to HMC for quaternary level care regardless of insurance status or ability to pay.

Patient Population:

Study subjects were trauma patients admitted to HMC from January 1, 2016 to December 31, 2019 and required at least 1 hour of ICU level care upon admission to select for higher severity of traumas. Inclusion criteria included: adults ages ≥18 years of age, and admission specifically for their traumatic injury. Exclusion criteria included: individuals with a documented housing status of migrant, foreign visitors or unknown; pediatric trauma patients (defined as age<18) due to unreliable housing status assessment; and missing Injury Severity Score (ISS) since the degree of injury could not be determined. Additionally, transitions in patient level of care were extracted from electronic medical record (EMR) data as the time of emergency department (ED) admission to transfer to subsequent units in order to only include patients who required ICU level care at the time of admission disposition. We defined ICU level of care at time of admission as patients admitted to an ICU upon admission within 6.5 hours from the time at which ED determined admission disposition, or admitted for surgical or procedural care (angiography suite, operating room (OR)) with subsequent ICU disposition; therefore, patients who were admitted to the floor, boarded early without requiring ICU level care, or discharged from the ED were excluded. Lastly, those who had incomplete unit times were also excluded.

Figure 1 depicts the flow diagram for defining the sample population. 9,088 patient encounters were obtained from the 2016-2019 trauma data set consisting of patients who required at least 1 hour of ICU level care. After enforcing our inclusion and exclusion criteria, the total sample population consisted of 7,666 patients with 399 patients documented as unhoused and 7,267 patients documented as housed.

Data Collection:

Patient information, inpatient location, and relevant time stamps were obtained from retrospectively extracted EMR data and prospectively maintained data from the trauma registry. Data collected included demographic information, injury characteristics, comorbidities, hospital unit transitions and interventions, complications, housing status, and in-hospital outcomes. Data was extracted using automated pull which was performed by trained research personnel blinded to patient outcomes. Missing values were reviewed manually, and resolution depended on variable type: excluded (missing housing status, missing ISS) or group median value allocated to missing patient information (modified CCI)). Infrequently, missingness was resolved through chart review (missing discharge date).

Exposure and Outcomes:
The primary exposure of interest was housing status at the time of hospital-admission. We used the variable "alternative housing" extracted from registry data to determine whether patients were "unhoused", based on the National Trauma Data Set definition as patients identified as homeless or lacking a zip code, versus "housed" upon admission. The alternative housing variable was further scrutinized by registry research personnel who evaluated housing status through prospective chart review and determined "Homeless" based on social history. Housing status was defined as a binary variable within our dataset (0/1 housed/unhoused).

The primary outcomes of interest included in-hospital all-cause mortality, ICU time to discharge, ventilator-free survival at 60 days, ICU-free survival time at 60 days, and hospital-free survival at 60 days. Ventilator, ICU, and Hospital days were defined as calendar days during which any portion of time spent receiving mechanical ventilation, in the ICU, or admitted to the hospital respectively, was counted as a full day. The 60-day interval was decided upon since 96.7% of patients' hospital course had terminated by that time, compared to 89.9% by day 30, while also minimizing the window of uncertainty that could result in misclassification due to loss of clinical follow-up. Mortality was defined as death during hospitalization. ICU time to discharge was the time from hospital admission to the first time point the patient was transferred to a lower level of care unit (floor, hospital discharge). Readmission to ICU was 5.2% of the sample population and was not included in total ICU time.

Covariates:
Five covariates were selected *a priori* as probable confounders between housing status and outcomes to be adjusted for: age, sex, injury mechanism, Injury Severity Score (ISS), and Charleston Comorbidity Index (CCI). Age was a continuous variable with range 18-102. Injury mechanism was a non-ordered categorized variable consisting of the top six causes of injury: falls, motor vehicle crash (including motorcycle accidents), pedestrian struck, assault, penetrating injury, and other. Other consisted of predominately hypothermia, self-harm, drowning, burns, and inhalation injuries. Lastly, ISS and CCI were coded as ordinal categories based on clinical practice.[40,41] We used the standard categorization of ISS with a score of 1-8 considered minor, 9-15 moderate, 16-24 severe, and ≥25 very severe injury.[40] As the standard CCI score factored in

age,[41] and age was already adjusting for, we used a modified CCI score that excludes the points scored for age to prevent collinearity. CCI scores were manually derived using the modified CCI score and a list of comorbidities per patient, categorized into score ranges: 0, 1-3, 4+, which corresponded with no comorbidities, some comorbidities, and several comorbidities, respectively. Data for all covariates were available except 458 patients did not have documented pre-existing complications, thus were given the population median CCI score of 0 (6.12% housed, 3.1% unhoused).

Statistical Analysis:

Descriptive statistics were used to summarize baseline characteristics with median [25^{th}-75^{th} IQR] listed for continuous variables and percentages for discrete variables. Univariate analysis was performed between unhoused and housed groups using ranksum or chi-square tests, as appropriate. We evaluated our time-to-event data using a left-truncated, right censored Kaplan-Meier survival curve to evaluate the observed difference in all cause in-hospital mortality between unhoused and housed patients. Time of injury was determined as the initial time (t_0), and truncation time was included for patients who presented at an outside hospital prior to arrival at HMC. Time was measured in days. Patients were followed until hospital discharge or death. Multivariable Cox proportional hazards regression was used to quantify the association between housing status and mortality while adjusting for covariates. Breslow method was used for ties. Proportional hazards assumption was assessed using Schoenfeld residuals and a global test demonstrated violation of proportionality. Our Cox model was modified to stratify for categorical ISS, categorical CCI, and injury mechanism variables in order to address the violation of the proportional hazards assumption. Mortality within the first 7 days was similarly assessed to demonstrate early deviation. Next, a Fine-Grey competing risk analysis was performed to evaluate if unhoused had quicker times to ICU discharge, with ICU discharge to floor or hospital discharge as the event of interest and mortality as the competing risk. Lastly, our three outcome-free survival measures at 60 days were analyzed using zero-inflated negative binomial regression. Survival free days were designated followed a similar protocol to McCaw et. al.[42] ICU-, Ventilator-, and Hospital-free survival times were defined as the amount of days accrued whereby patients were not on the ventilator, in the ICU, or in the hospital at 60 days, respectively. Patients who either died while in the ICU, on mechanical ventilation, or during hospitalization, or who remained in that state at day 60, were assigned zero ICU-free, ventilator-free, or hospital-free survival days, respectively. Among patients who survived past the outcome of interest, outcome-free survival was defined as the time from ICU discharge, liberation from mechanical ventilation, or hospital discharge to either observed death or day 60, whichever occurred first. Zero-inflated negative binomial regression was decided upon given a higher AIC score instead of Poisson regression, due to a significant proportion of patients having zero survival free days. All tests performed were two-sided, with a p-value threshold of 0.05 and 95% confidence intervals reported. All statistical and data analyses were performed using STATA 18.0.

Power:
The minimal detectable effect was determined to be 0.551 using n1=400 as an estimate of unhoused patients, n2=7,500 as an estimate of housed patients, an alpha=0.05, power=0.8, and event estimate of 10%.

Post Hoc Analysis:
In order to determine possible underlying causes for our findings, we performed a post hoc analysis of the rate of hospital complications, time to complications, time from complications to death, rate of comfort care measures, and percentage of brain deaths comparing housed to unhoused patients. In-hospital complications were categorized as cardiovascular defined as stroke, pulmonary embolism, deep vein thrombosis, myocardial infarction, or cardiac arrest; acute renal failure; acute respiratory distress syndrome; ventilator-associated pneumonia (VAP); other infections including Clostridioides difficile, community-acquired urinary tract infection (CAUTI), central line-associated bloodstream infection (CLABSI), deep and superficial surgical site infections, organ space infections, empyema, sepsis, osteomyelitis, and urinary tract infection; and return to the operating room (RTOR). The percentage of each complication as well as the mean time from admission to complication diagnosis was analyzed for housed and unhoused patients using chi-squared test and t-test, respectively. For patients who died, the mean time from complication to death for unhoused and unhoused patients was calculated using a t-test. To assess whether differences in mortality rate were due to differences in goals-of-care discussions between housed and unhoused patients, we analyzed differences in the percentage of comfort care measures, brain deaths, and pre-hospitalization advanced directives using chi-squared tests. Comfort care measures were defined as patients whose care transitioned to comfort focused, often resulting in palliative extubation. Brain death was declared by two physicians after standard testing. Comfort care measures and brain death were assess in patients who died while the rate of pre-hospital advanced directives was compared between all housed and unhoused patients using a chi-square test.

Sensitivity Analysis:
To evaluate a more severely injured subpopulation within the sample cohort, we constructed Kaplan Meier curve for all-cause in-hospital mortality and adjusted Cox regression using only patients who required two or more ventilator days, by housing status. Additionally, to factor in potential for patients dying shortly after hospitalization, we included patients whose dispositions were "hospice" as well as the "morgue", and re-analyzed the Kaplan Meier curve and adjusted Cox regression.

Results:

Descriptive Statistics
Of the 7,666 patients included, 399 were unhoused and 7,267 were housed. The sample population's descriptive statistics can be found in Table 1. Our cohort consisted of predominately males (70.5%) and of White race (79%). Unhoused patients were younger with a median age 45

(IQR 33, 56) compared to housed patients with a median age 53 (IQR 33, 70). Of the five most common mechanisms of injury, housed patients had higher falls (37% vs. 26%) and motor vehicle crashes (31% vs 10%), while unhoused patients had higher numbers of pedestrian struck (8% vs 21%), assault (5% vs. 17%), and penetrating injuries (10% vs. 15%). Injuries were broadly distributed with slightly more "Very Severe" ISS category for housed compared to unhoused (35% vs 31%), and slightly more "Severe" ISS category for unhoused (28% vs. 31%). Within our sample population, both housed and unhoused had similar Body Region AIS scores, with specifically no significant difference in Head AIS scores (77% vs. 80%). Housed had slightly more known preadmission comorbidities compared to unhoused. We found that unhoused patients presented in shock more often with 7% having an initial emergency room systolic blood pressure (SBP) <90mmHg, compared to 5% for housed (p=0.03). Additionally, unhoused had slightly greater packed red blood cell (RBC) transfusion needs (8% required 5-9 units compared to 4% in housed). Unhoused also required more emergency laparotomies (8% vs. 13%). Housed patients were more commonly discharged to a home (53% vs. 40%) or to subacute nursing facilities (20% vs. 5%), while unhoused were more commonly discharged to the street or a shelter (1% vs. 23%). There were more unhoused patients who were discharged against medical advice (AMA) (1% vs. 8%), however, both housed and unhoused AMA patients had a median ICU LOS 2 days (IQR 1, 4), while unhoused had a greater hospital LOS (median 12, IQR 5, 28) compared to housed (median 6, IQR 3, 12). Unhoused patients had slightly longer median length of hospital stay (8 days vs. 10 days), as well as on average more ventilator days (0 vs. 1 day), but similar median ICU days (2 vs. 2 days). There was no difference in the percentage of patients who were readmitted to the ICU in either group. Housed patients had a higher mortality rate compared to unhoused (10.3% vs. 6.8%), without a significant difference in comfort care related deaths, brain deaths, or death due to DNR status.

The unadjusted comparisons between housed and unhoused for each listed category above demonstrated significant differences in age, sex, race, mechanism of injury, ISS, CCI score, initial emergency room SBP<90mmHg, RBC transfusions in the first 24 hours, number of emergency laparotomies, discharge disposition, hospital LOS, median number of ventilator days, and mortality. No significant difference was identified for Body Region AIS score, median number of ICU days, and readmission rate to the ICU.

Survival Analysis and Cox Regression

A Kaplan-Meier Survival curve was produced to visualize the observed survival times for all-cause in-hospital mortality between housed and unhoused trauma patients, seen in Figure 2. Of the 27 total unhoused deaths, 26 of them took place prior to hospital day 41, with one single death at hospital day 103. Conversely, there were 748 deaths for housed patients steadily across the hospitalization. The 90th percentile survival time was 11 days for housed and 32 days for unhoused. A log-rank test showed a significant difference between the two survival curves (p=0.003). A Cox regression model stratified by ISS categories, Injury mechanism categories, and CCI categories, and adjusted for age and sex demonstrated that unhoused patients had a 34.5% lower hazard of all-cause mortality compared to housed trauma patients (HR 0.66 95% CI: 0.44-0.98, p-value=0.04). A similar Kaplan-Meier Survival curve (Figure 3) and Cox regression was performed for the first 7 hospital days. A log-rank test demonstrated a significant difference between the two survival curves in the first 7 days ($p=0.009$). The Cox regression model with the same stratification and adjustments showed evidence of a 42% lower hazard in all-cause mortality in the unhoused trauma patients compared to the housed (HR 0.58, 95% CI: 0.35-0.98, p-value=0.04).

Competing Risk Analysis

An adjusted Fine-Grey model with the event of interest being ICU discharge and the competing risk being mortality was modeled by housing status. Of the patients who survived their ICU course, there was no significant difference in rate to ICU discharge between housed and unhoused patients (SHR 0.98, 95% CI: 0.88-1.1, p-value=0.75). A cumulative incidence plot in Figure 4 depicts this relationship.

Zero-Inflated Negative Binomial Regression

Outcome-Free Survival days for Ventilator days, ICU days, and Hospital days at 60 days were calculated and analyzed by housing status using Zero-Inflated Negative Binomial Regression with the same adjustment variables. Neither the rate of ventilator-free survival nor ICU-free survival at 60 days differ between unhoused and housed patients (IRR=1.004, 1.004; 95% CI: 0.98-1.03, 0.99-1.02; p-value=0.73, 0.60). However, unhoused trauma patients had significantly lower incidence of hospital-free survival at 60-days compared to housed trauma patients (IRR=0.95, 95% CI: 0.92-0.97, p-value<0.001). The cumulative density plots between housed and unhoused patients for each outcome-free survival measure is depicted in Figure 5.

Post Hoc Analysis

The percentages and time to complications by housing status are depicted in Table 2. There was no statistically significant difference in the percentage of each complication by housing status, nor the mean time to complication diagnosis. For the 775 patients who died, 271 housed patients had in-hospital complications (36.2%), and 10 unhoused patients had in-hospital complications (37%). The mean time from complication development to death was 5.67 days for housed and 9.5 days for unhoused, which was not significantly different (p-value=0.13).

Housed patients had a greater percentage of advanced directives upon presenting to the hospital (n=263, 3.62%) compared to unhoused (n=2, 0.5%) which was significantly different (p-value=0.001). However, there was no significant difference in the number of advanced directives between housed and unhoused patients who died (p-value=0.22). Of the 775 patients who died, 542 housed (72.5%) and 17 unhoused (63%) patients died with comfort care measures, which was not significantly different (p-value=0.12). Similarly, 98 housed (13.1%) and 7 unhoused (25.9%) patients died by brain death declaration, which was not statistically significantly different (p-value=0.056).

Sensitivity analysis

Assessing the subcohort of patients who are more severely injured, 2,852 patients (2,678 housed, 174 unhoused) had two or more ventilator days, with 549 deaths (525 housed, 24 unhoused). The

Kaplan Meier Curve is depicted in Figure 6. A log-rank test shows a statistically significant difference between the two survival curves (0.03). The Cox regression model demonstrated that unhoused severe trauma patients have 38.3% increased survival compared to housed severe trauma patients when stratifying by categorical ISS, categorical injury mechanism, categorical CCI, and adjusting for age and sex (HR: 0.62, 95% CI: 0.40-0.95, p-value=0.03).

Similarly, we combined deaths with patients whose disposition was hospice, resulting in 803 total presumed deaths (775 housed, 28 unhoused). The Kaplan Meier Curve is depicted in Figure 7. A log-rank test demonstrated significant difference between the two curves (p-value=0.003). An adjusted Cox regression model showed that unhoused trauma patients had 33.5% lower hazard ratio when factoring in hospice discharges compared to housed trauma patients (HR 0.67, 95% CI: 0.45-0.99, p=0.04).

Discussion:

In this retrospective cohort study, unhoused trauma patients arrived at the hospital in more critical condition with a higher shock index, requiring more emergency laparotomies upon admission, and more transfusions than housed trauma patients. Despite higher severity early on, unhoused patients did not have any difference in the rate of ICU discharge, ICU-free survival at 60 days, or Ventilator-free survival at 60 days compared to housed trauma patients, suggesting similar critical care needs. However, we found that unhoused patients had a 34.5% lower hazard of all-cause in-hospital mortality compared to housed trauma patients, even when adjusting for age, sex, ISS, injury mechanism, and modified CCI score. This difference in mortality by housing status could not be explained by disparities in complication percentages, time to complication development, time to death after a complication, percentage of brain death, nor percentage of comfort care measures. Additionally, unhoused patients had less hospital-free survival at 60 days, presumably secondary to challenges with discharge disposition as seen in Silver et al, resulting in longer observed times than housed patients, weakening the argument that unhoused deaths were under-observed. While there was a higher percentage of AMA discharges for unhoused patients (8%) compared to housed patients (1%), the median time to AMA discharge was twice as long in unhoused compared to housed, also suggesting that the greater observed time among AMA discharged unhoused patients reduces the risk of unwitnessed death due to a shortened hospital LOS. Moreover, the difference in mortality between housed and unhoused patients was observed as early as in the first 7 hospital days. The mortality findings were consistent when validated within a more severe subset of our patients. Our findings supported our hypothesis that unhoused patients are more resilient to acute stressors.

It is surprising that unhoused patients, who were in worse clinical condition, were able to overcome the acuity of their injury to have similar critical care needs and greater in-hospital survival. The disproportionately higher survival in unhoused patients, especially when seen early within the hospital course, suggests they are more resilient after an acute traumatic injury. The mechanism for this resilience cannot be determined from our data, though it provides evidence that supports the potential theories that allostatic overload may provide some protective effects to subsequent acute stressors through stress inoculation and adaptive calibration. At the same time, another explanation may be that the unhoused trauma patients in our cohort may represent a form of resilient “survivor bias”, whereby prolonged exposure to adversity has selected for individuals with greater physiological or psychological resilience in the face of a subsequent acute stressor, leading to a selection bias similar to the “healthy worker survivor” effect.[43] Thus, our data may be supporting that the baseline resilience is higher in unhoused patients due to survivorship bias. Nevertheless, in either case our study provides evidence that unhoused trauma patients are an important population that may help delineate the underlying biological mechanisms and determinates of health that can increase ones’ resilience to acute stressors.

Our study has several strengths. By using time-to-event analysis to evaluate mortality, we were able to understand the nuances of how mortality risk evolved over the hospitalization, whereby prior research used logistic regression models. Additionally, we controlled for key clinical variables using multivariable modeling, thus minimizing confounding effect and with score system definitions consistent with clinical utility. Our study’s large cohort (N=7,667) allowed for robust comparisons, and by focusing on a single-center setting we ensured consistency in care protocols. Lastly, robust clinical data allowed us to assess not only outcomes and their timing but also clinical factors such as complications and comfort care measures to determine whether differences in clinical practice could explain our findings.

One of the primary limitations of our study was the determination of the housing status variable. Trauma patients were categorized as homeless/unhoused by clinical coordinators who reported housing status through chart review. Coordinators were trained to not rely on lack of a residency zip code, but rather to assess whether participants lacked stable housing despite what home address was reported in the EMR. Homelessness is a complicated social situation that can encompass a broad range of living situations including those who are chronically unsheltered, living in shelters, couch surfing, and living out of a car or other types of transportation, etc. Our data lacks the temporality of homelessness, and is specific to individuals who are determined to be chronically unsheltered or were living in shelters at the time of admission; it doesn’t differentiate between the full breadth of homelessness including those who may be episodically homeless but not at the time of admission, who may be transitionally homeless but are generally housed, and those at risk of homelessness in the near future. As we have excluded pediatric traumas (<18), we also were unable to evaluate the incidence and difference in outcomes within our population for a portion of homeless youth (ages 12-24), which is a uniquely vulnerable and growing population.

Other limitations included a small sample of unhoused patients compared to housed patients, retrospective study design, possible residual confounding of covariates, and that findings are specific to the WWAMI region which may not be generalizable. Additionally, while we were interested in understanding the degree of resilience between housed and unhoused populations, we could only do so through proxies of resilience (ICU LOS, ventilator days, hospital LOS, mortality) within our data. Resilience is also a multifactorial, biologically complex process with current challenges in definition and measurements. While clinical outcomes were reasonable proxies to measuring resilience, our data has limited granularity regarding temporal changes in clinical status over the course of a patient's hospitalization, which would've been necessary for a better measure of resilience.

Future directions include looking at biological markers across the hospital stay that may help elucidate physiological causes for these mortality differences. We recommend assessing markers that have been previously studied within the stress response and resilience literature including immune markers (IL-6, TNF-α), hormone levels (cortisol, catecholamines), and heart rate variability.

Conclusion:

Unhoused trauma patients had significantly lower all-cause in-hospital mortality compared to housed trauma patients, despite having arrived in more critical condition. These findings suggest that unhoused individuals are more resilient to acute stressors, potentially due to stress inoculation, adaptive calibration, or survivorship bias. Unhoused trauma patients are a critical population that may delineate the biological mechanisms and determinants of health that enhance resilience to acute stressors. Time-to-event analysis can be a useful approach for capturing both the occurrence and timing of outcomes in patients with prolonged hospitalizations

Tables and Figures:

Figure 1. Study Inclusion and Exclusion Flow Diagram

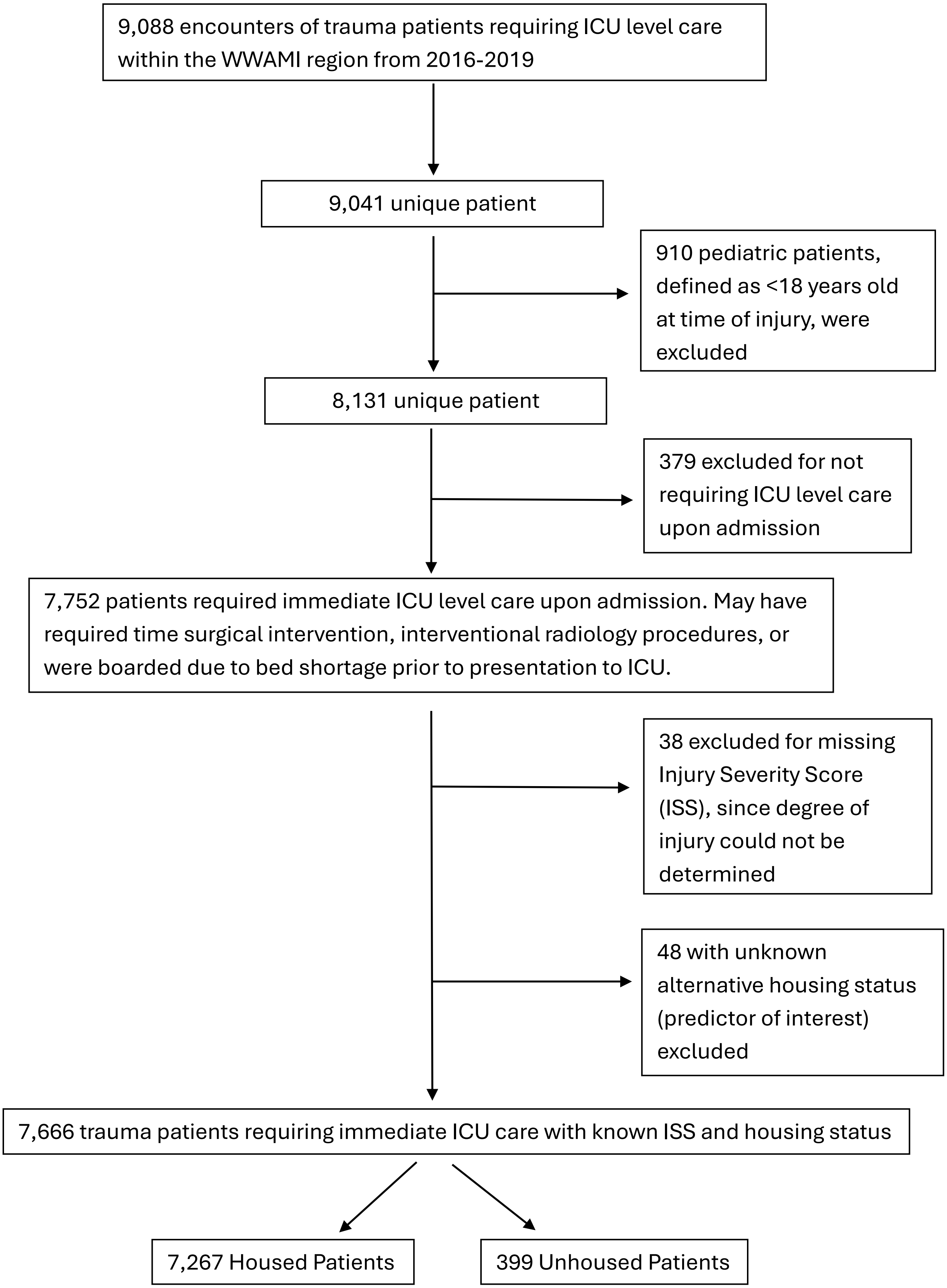

Figure 2. Kaplan-Meier All-Cause Survival Estimates of Housed and Unhoused Trauma Patients during Hospitalization

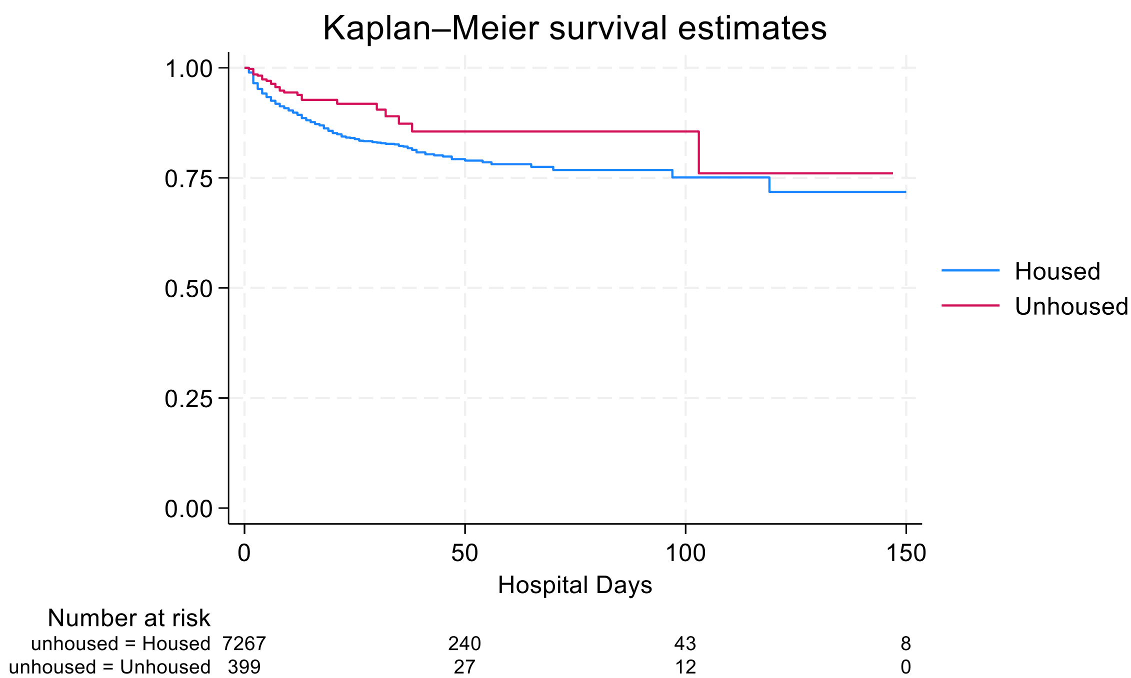

Figure 3. Kaplan-Meier All-Cause Survival Estimates of Housed and Unhoused Trauma Patients during First 7 Days Post-Injury

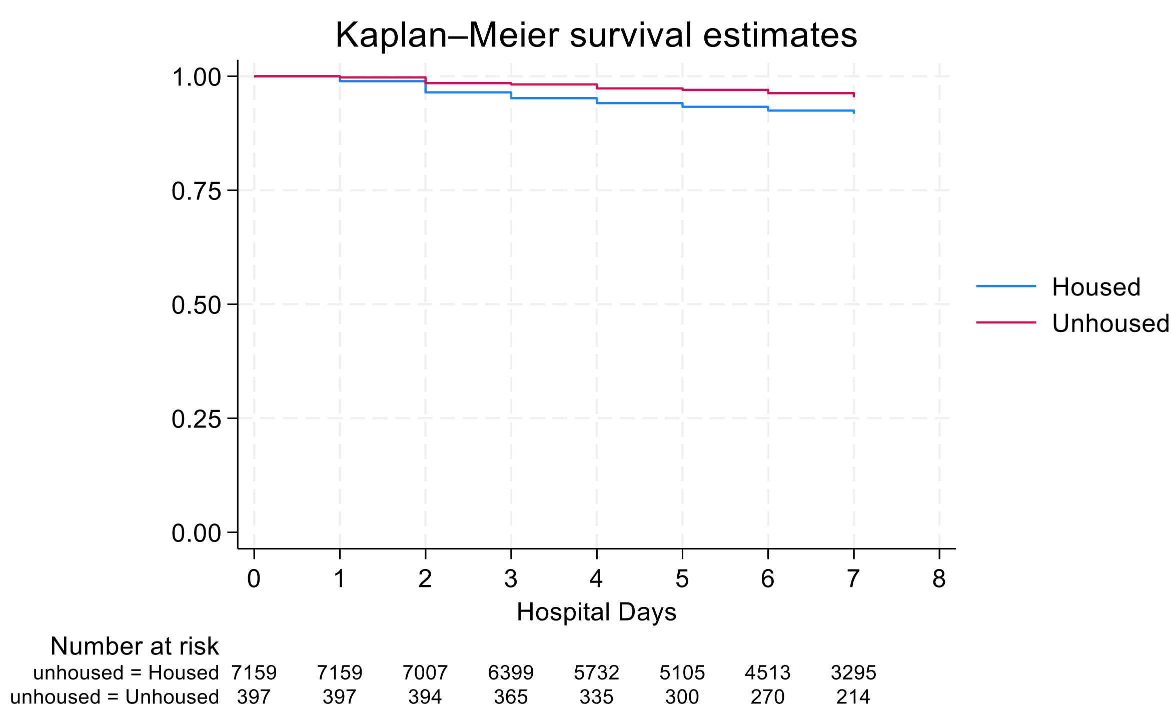

Figure 4. Cumulative Incidence Rate of ICU Discharge by Housing Status

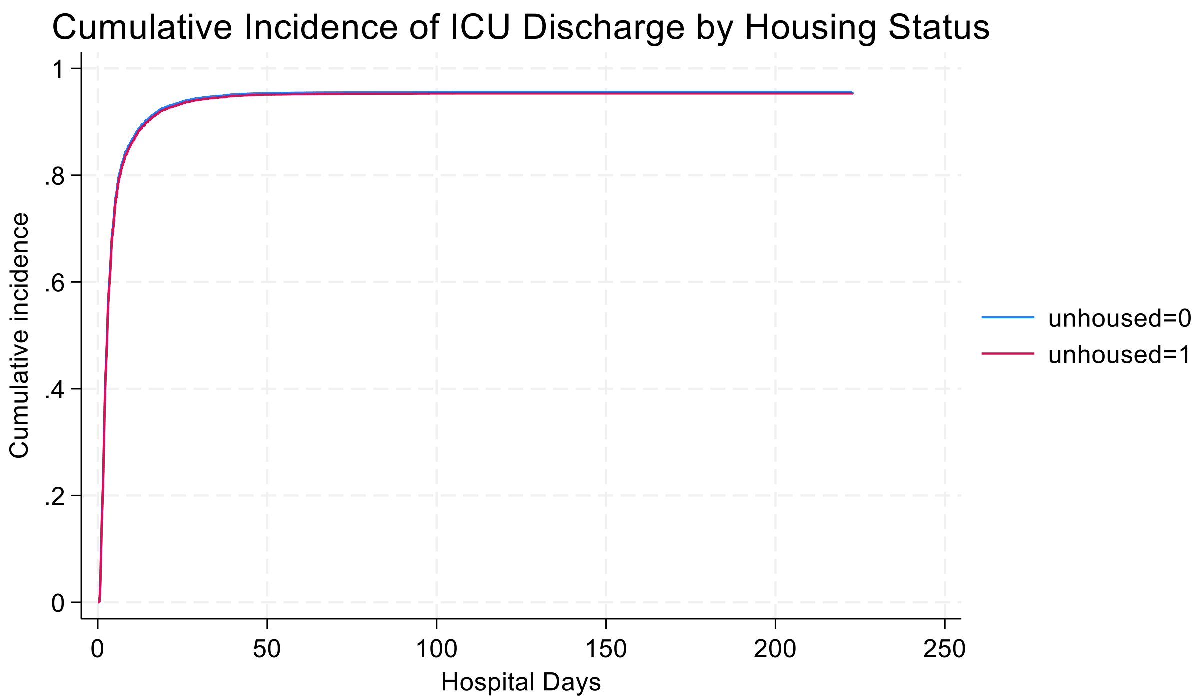

Figure 5. Cumulative Density Plots for Ventilator-, ICU, and Hospital-Free Survival Days by Housing Status

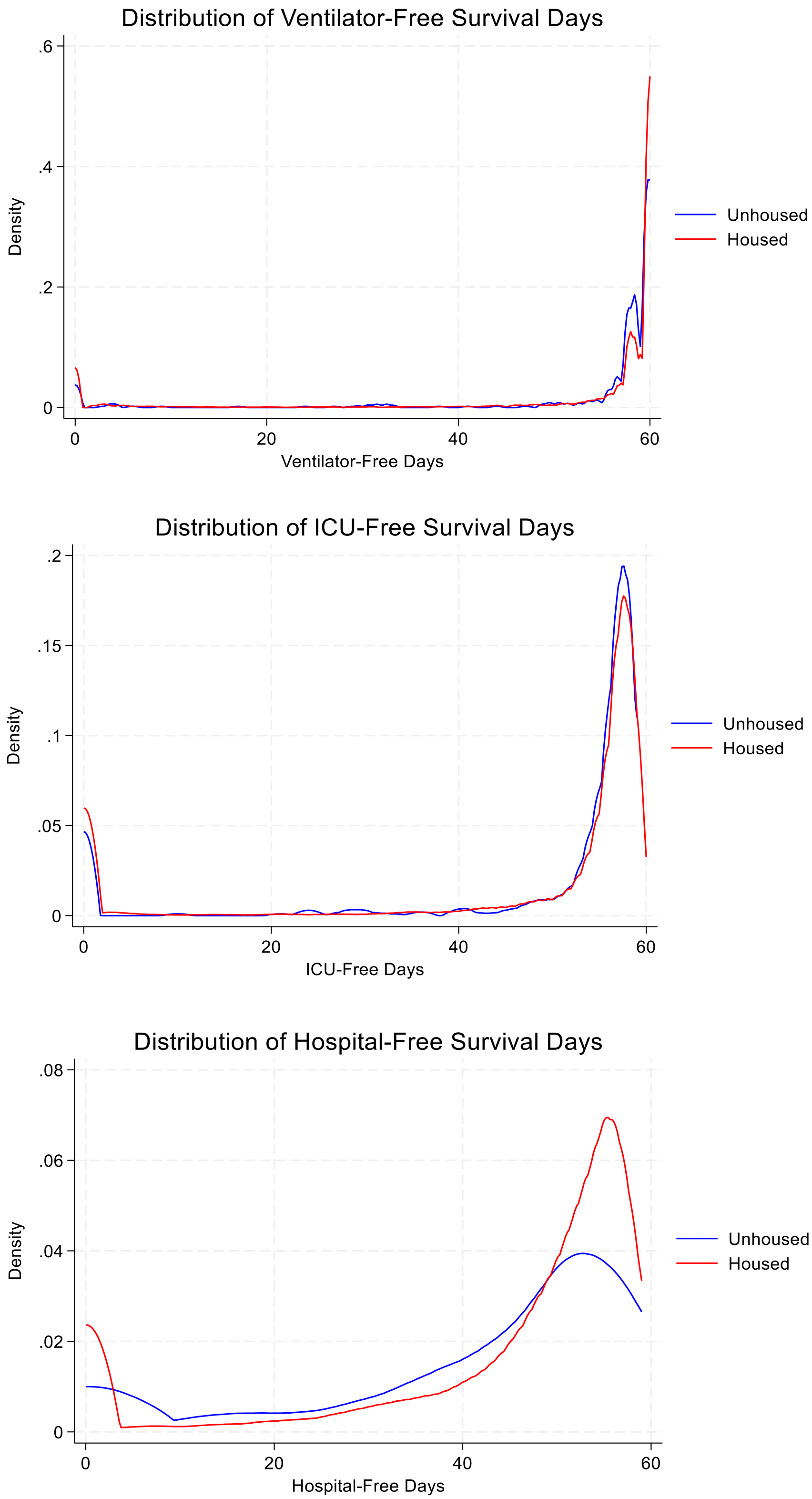

Figure 6. Kaplan-Meier All-Cause Survival Estimates amongst Severe Trauma Patient Subgroup by Housing Status

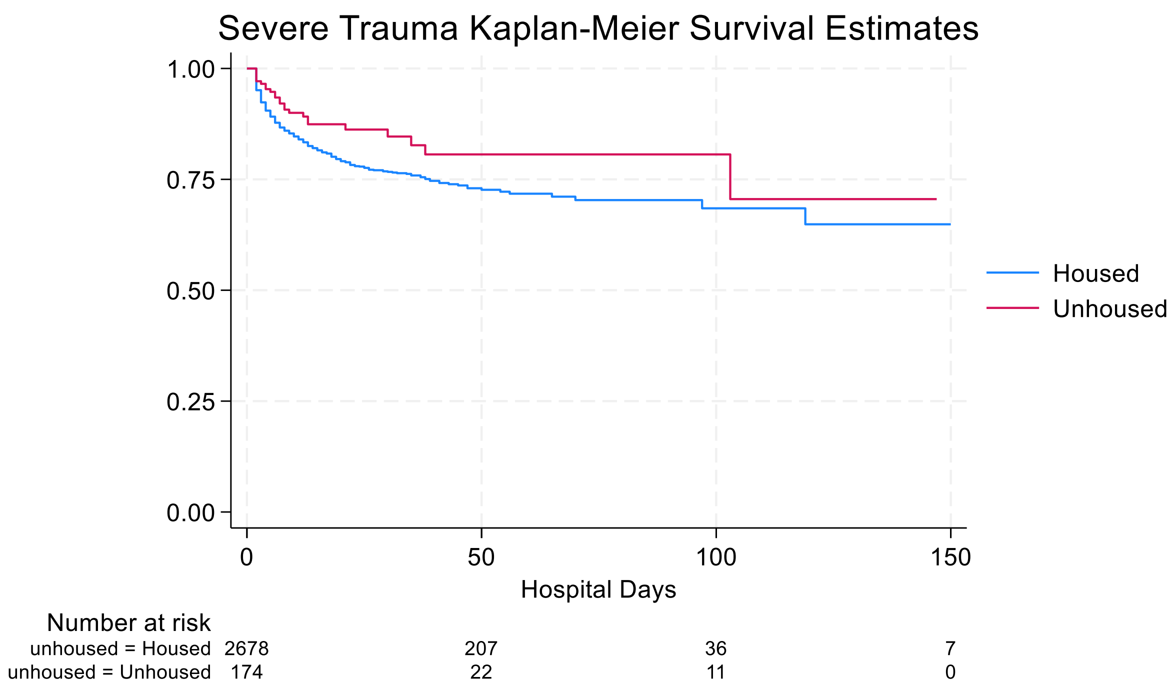

Figure 7. Kaplan-Meier All-Cause Survival Estimates amongst Trauma Deaths and Hospice Discharges by Housing Status

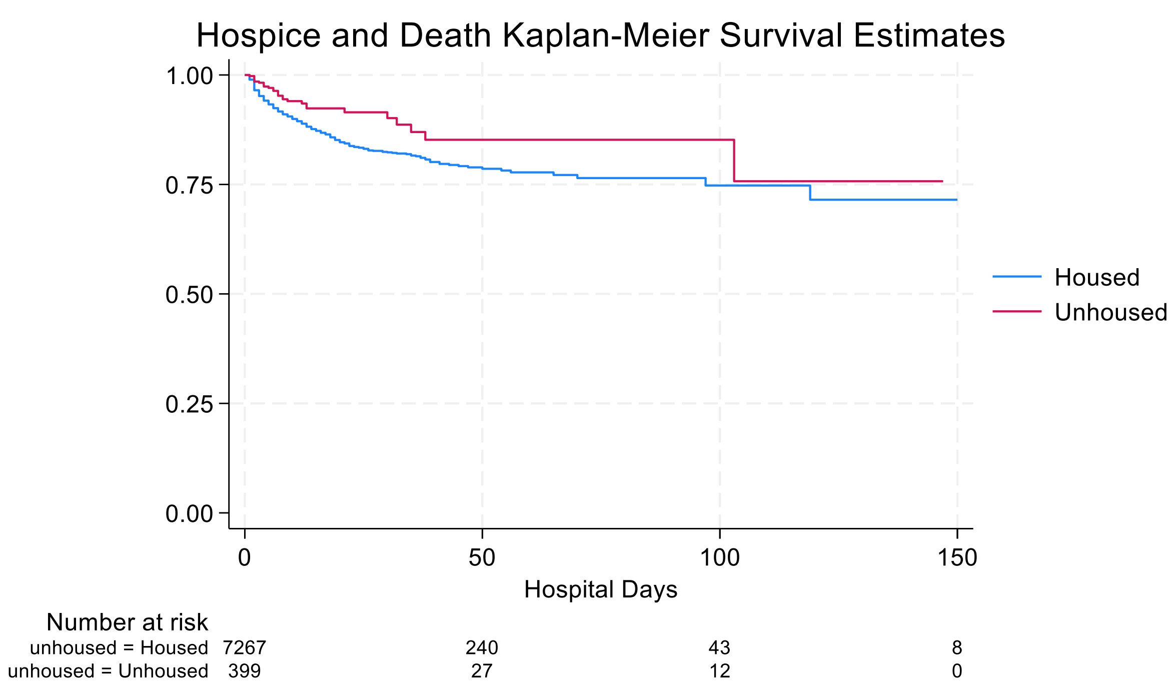

Table 1. Cohort Demographics and Outcomes for WWAMI Trauma Patients requiring ICU Level Care from 2016-2019, by Housing Status

Characteristics	Housed	Unhoused	p-value
N=	7,267	399	
Age, n (IQR, years)	53 (33, 70)	45 (33, 56)	<0.001
Sex, n (%)			<0.001
Female	2,189 (30%)	70 (18%)	
Male	5,078 (70%)	329 (82%)	
Race, n (%)			<0.001
American Indian or Alaska	205 (3%)	27 (7%)	
Asian	468 (6%)	9 (2%)	
Black	549 (8%)	66 (17%)	
White	5,781 (80%)	280 (70%)	
Native Hawaiian or Pacific Islander	71 (1%)	1 (0%)	
Other	3 (0%)	0 (0%)	
Not documented	190 (3%)	16 (4%)	
Mechanism of Injury, n (%)			<0.001
Fall	2,729 (37%)	103 (26%)	
Motor vehicle/Motorcycle Crash	2,249 (31%)	41 (10%)	
Pedestrian Struck	571 (8%)	84 (21%)	
Assault	361 (5%)	67 (17%)	
Penetrating	692 (10%)	58 (15%)	
Other	665 (9%)	46 (11%)	
Injury Severity Score, n (%)			0.027
Mild (1-8)	699 (10%)	54 (13%)	
Moderate (9-15)	1,953 (27%)	99 (25%)	
Severe (16-24)	2,067 (28%)	123 (31%)	
Very Severe (≥25)	2,548 (35%)	123 (31%)	
Body Regions AIS≥3, n (%)[1]			
Head	2,673 (77%)	135 (80%)	0.294
Face	183 (12%)	6 (8%)	0.158
Neck	405 (62%)	26 (60%)	0.854
Chest	2,748 (79%)	149 (80%)	0.889
Abdomen	949 (63%)	60 (60%)	0.944
Spine	933 (38%)	35 (31%)	0.782
Upper Extremity	235 (12%)	15 (15%)	0.646
Lower Extremity	1,555 (68%)	87 (70%)	0.794
Charleston Comorbidity Index (CCI), n (%)			<0.001
0	5,134 (71%)	320 (80%)	
1-3	1,803 (25%)	72 (18%)	
≥4	330 (4%)	7 (2%)	
Initial ED SBP <90mmHg, n (%)	349 (5%)	29 (7%)	0.027
RBC Transfusion First 24 hours, n (%)			0.008
None	5,630 (77%)	290 (73%)	
1-4 units	1,156 (16%)	68 (17%)	
5-9 units	299 (4%)	30 (8%)	
10+ units	182 (3%)	11 (3%)	
Emergency Laparotomy, n (%)	565 (8%)	50 (13%)	0.001
Discharge Disposition			<0.001
Home	3,885 (53%)	160 (40%)	

Inpatient Rehab	662 (9%)	20 (5%)	
Subacute Nursing Facility	1,485 (20%)	20 (5%)	
Long-Term Care Facility	76 (1%)	3 (<1%)	
AMA[3]	71 (1%)	32 (8%)	
Hospice or Morgue	773 (11%)	28 (7%)	
Street or Shelter	37 (1%)	92 (23%)	
Jail	74 (1%)	7 (2%)	
Other[4]	204 (3%)	16 (4%)	
Outcomes			
Hospital LOS, n (IQR)	8 (4, 15)	10 (5, 21)	<0.001
ICU Days, n (IQR)	2 (1, 5)	2 (2, 5)	0.221
Ventilator Days, n (IQR)	0 (0, 2)	1 (0, 2)	0.008
Readmit to ICU, n(%)[5]	380 (5.2%)	19 (4.7%)	0.682
Died (%)	748 (10.3%)	27 (6.8%)	0.023
Comfort Care	568	17	0.124
Brain Death	98	7	0.056
DNR	47	2	0.814

Continuous data presented as median (IQR); discrete data as number (%)
Univariate analysis using rank sum test for continuous variable and chi2 for discrete
[1]Body regions with frequency <10% are not shown including external injuries
[2]Other injuries include hypothermia, self-harm, drowning, burns, and inhalation injuries
[3]Median ICU LOS 2 days (IQR 1, 4) for both housed and unhoused AMA, but greater Hospital LOS in unhoused (median 12, IQR 5, 28) than housed (median 6, IQR 3, 12)
[4]Other dispositions include detoxication facilities, psychological aftercare, and organized ambulatory care facility (OACF)
[5]Readmission to any ICU during initial trauma admission
Abbreviations: Emergency Department (ED), Systolic Blood Pressure (SBP), Red blood cell (RBC), Against Medical Advice (AMA), intensive care unit (ICU), length of stay (LOS)

Table 2. In-Hospital Complications Percentages and Mean Rates by Housing Status

Hospital Complications	Total Complication Rate	n, % Unhoused (N=399)	n, % Housed (N=2,767)	p-value[1]	Time to Complications (days), unhoused[2]	Time to Complications (days), housed[2]	p-value[3]
Cardiovascular	7.5%	21 (5.3%)	533 (7.6%)	0.083	2.6	4.8	0.227
ARF	1.1%	4 (1%)	82 (1.1%)	0.816	4	5.1	0.716
ARDS	1.8%	6 (1.5%)	132 (1.8%)	0.647	5	4.3	0.712
VAP	3.3%	11 (2.7%)	243 (3.3%)	0.524	6.8	7.6	0.777
Other Infections	5.8%	28 (7%)	419 (5.8%)	0.299	10	13.5	0.194
RTOR	2.3%	9 (2.3%)	167 (2.3%)	0.956	12.1	9.7	0.602

[1]p-value calculated using chi2 comparing complication percentage by housing status
[2]Mean time calculated from first complication for given category for patients with more than one complication within a given category
[3]p-value calculated using t-test for mean time to complication by housing status
Abbreviations: ARF=Acute Renal Failure, ARDS=Acute Respiratory Distress Syndrome, VAP=Ventilator-Associated Pneumonia, RTOR=Return to Operating Room

References:

1. Dimsdale, J E; Mills, P; Patterson, T; Ziegler, M; Dillon, E. Effects of chronic stress on beta-adrenergic receptors in the homeless. Psychosomatic Medicine 56(4):p 290-295, July 1994.
2. Mariotti A. The effects of chronic stress on health: new insights into the molecular mechanisms of brain-body communication. Future Sci OA. 2015 Nov 1;1(3):FSO23. doi: 10.4155/fso.15.21. PMID: 28031896; PMCID: PMC5137920.
3. Lu S, Wei F, Li G. The evolution of the concept of stress and the framework of the stress system. Cell Stress. 2021 Apr 26;5(6):76-85. doi: 10.15698/cst2021.06.250. PMID: 34124582; PMCID: PMC8166217.
4. Robert-Paul Juster, Bruce S. McEwen, Sonia J. Lupien. Allostatic load biomarkers of chronic stress and impact on health and cognition. Neuroscience & Biobehavioral Reviews. Volume 35, Issue 1, 2010. Pages 2-16. ISSN 0149-7634, https://doi.org/10.1016/j.neubiorev.2009.10.002.
5. Jenny Guidi, Marcella Lucente, Nicoletta Sonino, Giovanni A. Fava; Allostatic Load and Its Impact on Health: A Systematic Review. *Psychother Psychosom* 15 December 2020; 90 (1): 11–27. https://doi-org/10.1159/000510696
6. S.M. Korte, J.M. Koolhaas, J.C. Wingfield, B.S. McEwen. The Darwinian concept of stress: benefits of allostasis and costs of allostatic load and the trade-offs in health and disease. Neurosci. Biobehav. Rev., 29 (2005), p. 3
7. S.J. Lupien, I. Ouellet-Morin, A. Hupbach, D. Walker, M.T. Tu, C. Buss, J. Pruessner, B. McEwen. Beyond the stress concept: allostatic load—a developmental biological and cognitive perspective. D. Cicchetti (Ed.), Handbook Series on Developmental Psychopathology (2006), p. 784
8. Gillespie SL, Anderson CM, Zhao S, Tan Y, Kline D, Brock G, et al. Allostatic load in the association of depressive symptoms with incident coronary heart disease: The Jackson Heart Study. *Psychoneuroendocrinology*. 2019Nov;109:104369. https://doi-org/10.1016/j.psyneuen.2019.06.020
9. Sabbah W, Watt RG, Sheiham A, Tsakos G. Effects of allostatic load on the social gradient in ischaemic heart disease and periodontal disease; evidence from the Third National Health and Nutrition Examination Survey. *J Epidemiol Community Health*. 2008May;62(5):415-20. https://doi-org/10.1136/jech.2007.064188
10. Nelson KM, Reiber G, Kohler T, Boyko EJ. Peripheral arterial disease in a multiethnic national sample: the role of conventional risk factors and allostatic load. *Ethn Dis*. 2007;17(4):669-75
11. Steptoe A, Hackett RA, Lazzarino Al, Bostock S, La Marca R, Carvalho LA, et al. Disruption of multisystem responses to stress in type 2 diabetes: investigating the dynamics of allostatic load. *Proc Natl Acad Sci USA*. 2014Nov;111(44):15693-8. https://doi-org/10.1073/pnas.1410401111
12. Allsworth JE, Weitzen S, Boardman LA. Early age at menarche and allostatic load: data from the Third National Health and Nutritional Examination Survey. *Ann Epidemiol.* 2005Jul;15(6):438-44. https://doi-org/10.1016/j.annepidem.2004.12.010
13. Bay E, Covassin T. Chronic stress, somatic and depressive symptoms following mild to moderate traumatic brain injury. *Arch Psychiatr Nurs*. 2012Dec;26(6):477-86. https://doi-org/10.1016/j.apnu.2012.06.002
14. Baldin E, Hauser WA, Pack A, Hesdorffer DC. Stress is associated with an increased risk of recurrent seizures in adults. *Epilepsia*. 2017Jun;58(6):1037-46. https://doi-org/10.1111/epi.13741
15. Abercrombie HC, Giese-Davis J, Sephton S, Epel ES, Turner-Cobb JM, Spiegel D. Flattened cortisol rhythms in metastatic breast cancer patients. *Psychoneuroendocrinology*. 2004Sep;29(8):1082-92. https://doi-org/10.1016/j.psyneuen.2003.11.003
16. Juster RP, Marin MF, Sindi S, Nair NP, Ng YK, Pruessner JC, et al. Allostatic load associations to acute, 3-year and 6-year prospective depressive symptoms in healthy older adults. *Physiol Behav*. 2011Aug;104(2):360-4. https://doi-org/10.1016/j.physbeh.2011.02.027
17. Kobrosly RW, van Wijingaarden E, Seplaki CL, Cory-Slechta DA, Moynihan J. Depressive symptoms are associated with allostatic load among community-dwelling older adults. *Physiol Behav*. 2014Jan;123:223-30. https://doi-org /10.1016/j.physbeh.2013.10.014
18. Glover DA. Allostatic load in women with and without PTSD symptoms. *Ann N Y Acad Sci*. 2006Jul;1071(1):442-7. https://doi-org/10.1196/annals.1364.039
19. Berger M, Juster RP, Westphal S, Amminger GP, Bogerts B, Schiltz K, et al. Allostatic load is associated with psychotic symptoms and decreases with antipsychotic treatment in patients with schizophrenia and first-episode psychosis. *Psychoneuroendorinology*. 2018Apr;290:35-42. https://doi-org/10.1016/j.psyneuen.2018.02.001

20. Adinoff B, Leonard D, Price J, Javors MA, Walker R, Brown ES, et al. Adrenocortical sensitivity, moderated by ongoing stress, predicts drinking intensity in alcohol-dependent men. *Psychoneuroendocrinology.* 2017Feb;76:67-76. https://doi-org/10.1016/j.psyneuen.2016.10.011
21. Gilbert LK, Breiding MJ, Merrick MT, et al. Childhood adversity and adult chronic disease: an update from ten states and the District of Columbia, 2010. *Am J Prev Med*. 2015;48(3):345-349. doi:10.1016/J.AMEPRE.2014.09.006
22. Jackson DB, Testa A, Vaughn MG, Camacho S, Henderson SC. The Social Determinants of Adverse Childhood Experiences: An Intersectional Analysis of Place, Access to Resources, and Compounding Effects. Published online 2022. doi:10.3390/ijerph191710670
23. Felitti VJ, Anda RF, Nordenberg D, Williamson DF, Spitz AM, Edwards V, Koss MP, Marks JS. Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. The Adverse Childhood Experiences (ACE) Study. Am J Prev Med. 1998 May;14(4):245-58. doi: 10.1016/s0749-3797(98)00017-8. PMID: 9635069.
24. Park ER, Luberto CM, Chad-Friedman E, Traeger L, Hall DL, Perez GK, Goshe B, Vranceanu AM, Baim M, Denninger Md PhD JW, Fricchione Md G, Benson Md H, Lechner SC. A Comprehensive Resiliency Framework: Theoretical Model, Treatment, and Evaluation. Glob Adv Health Med. 2021 Mar 24;10:21649561211000306. doi: 10.1177/21649561211000306. PMID: 34377598; PMCID: PMC8327002.
25. Durbin A, Nisenbaum R, Kopp B, O'Campo P, Hwang SW, Stergiopoulos V. Are resilience and perceived stress related to social support and housing stability among homeless adults with mental illness? Health Soc Care Community. 2019 Jul;27(4):1053-1062. doi: 10.1111/hsc.12722. Epub 2019 Feb 7. PMID: 30734374.
26. Schetter CD, Dolbier C. Resilience in the Context of Chronic Stress and Health in Adults. Soc Personal Psychol Compass. 2011 Sep;5(9):634-652. doi: 10.1111/j.1751-9004.2011.00379.x. PMID: 26161137; PMCID: PMC4494753.
27. Brown, L., Cohen, B., Costello, R., Brazhnik, O. and Galis, Z. (2023), Conceptualizing a resilience research framework at The National Institutes of Health. Stress and Health, 39: 4-9. https://doi-org.offcampus.lib.washington.edu/10.1002/smi.3260
28. Adriana Feder, Sharely Fred-Torres, Steven M. Southwick, Dennis S. Charney. The Biology of Human Resilience: Opportunities for Enhancing Resilience Across the Life Span. Biological Psychiatry, Volume 86, Issue 6,2019. Pages 443-453, ISSN 0006-3223. https://doi.org/10.1016/j.biopsych.2019.07.012.
29. Wadsworth ME. Development of Maladaptive Coping: A Functional Adaptation to Chronic, Uncontrollable Stress. Child Dev Perspect. 2015 Jun 1;9(2):96-100. doi: 10.1111/cdep.12112. PMID: 26019717; PMCID: PMC4442090.
30. de Baca TC, Wahl RA, Barnett MA, Figueredo AJ, Ellis BJ. Adversity, Adaptive Calibration, and Health: The Case of Disadvantaged Families. Adapt Human Behav Physiol. 2016 Jun 1;2(2):93-115. doi: 10.1007/s40750-016-0042-z. Epub 2016 Feb 1. PMID: 27175327; PMCID: PMC4860814.
31. Schulz AJ, Mentz G, Lachance L, Johnson J, Gaines C, Israel BA. Associations between socioeconomic status and allostatic load: effects of neighborhood poverty and tests of mediating pathways. *Am J Public Health*. 2012 Sep;102(9):1706–14. https://doi-org.offcampus.lib.washington.edu/10.2105/AJPH.2011.300412
32. Moledina A, Magwood O, Agbata E, Hung JH, Saad A, Thavorn K, Pottie K. A comprehensive review of prioritised interventions to improve the health and wellbeing of persons with lived experience of homelessness. Campbell Syst Rev. 2021 Jun 24;17(2):e1154. doi: 10.1002/cl2.1154. Update in: Campbell Syst Rev. 2019 Sep 12;15(3):e1048. doi: 10.1002/cl2.1048. PMID: 37131928; PMCID: PMC8356292.
33. Baggett TP, Liauw SS, Hwang SW. Cardiovascular Disease and Homelessness. J Am Coll Cardiol. 2018 Jun 5;71(22):2585-2597. doi: 10.1016/j.jacc.2018.02.077. PMID: 29852981.

34. *Health conditions among individuals with a history of homelessness research brief*. ASPE. (n.d.). https://aspe.hhs.gov/reports/health-conditions-among-individuals-history-homelessness-research-brief-0
35. Casey M. Silver, M. (2023, June 29). *Injury patterns and hospital admission after trauma among people experiencing homelessness*. JAMA Network Open. https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2806588
36. Fazel, S., Pearson, D. A., Morris, D. M., Yeniocak, S., Topolovec-Vranic, J., Cameron, P., Haider, A. H., Southern, W. N., Moore, G., Kaufman, E., Nunn, J., Cubbin, C., … Kim, D. K. (2020, February 20). *Trauma in adults experiencing homelessness*. Injury. https://www.sciencedirect.com/science/article/abs/pii/S0020138320301595

37. Brendin R Beaulieu-Jones, Sophia M Smith, Anna J Kobzeva-Herzog, Maia R Nofal, Monica Abou-Ezzi, Miranda Melici, Priya Desai, Ann Fefferman, Tracey A Dechert, Megan G Janeway, Sabrina E Sanchez. Association of houselessness and outcomes after traumatic injury: A retrospective, matched cohort study at an urban, academic level-one trauma center. Injury, 2025,112214. ISSN 0020-1383. https://doi.org/10.1016/j.injury.2025.112214.
38. Silver CM, Thomas AC, Reddy S, et al. Morbidity and Length of Stay After Injury Among People Experiencing Homelessness in North America. *JAMA Netw Open.* 2024;7(2):e240795. doi:10.1001/jamanetworkopen.2024.0795
39. Melissa S. Kovacs, Daniel J. Cucher, Nicholas Thiessen, Vafa Ghaemmaghami, John M. Watt, Charles K. Hu. Outcomes and characteristics differ between homeless and housed trauma patients following the COVID-19 pandemic. Injury, Volume 56, Issue 1, 2025, 112062, ISSN 0020-1383, https://doi.org/10.1016/j.injury.2024.112062.
40. Paul Reynolds, Joseph A. Scattoloni, Peter Ehrlich, Franklyn P. Cladis, Peter J. Davis, CHAPTER 30 - Anesthesia for the Pediatric Trauma Patient, Editor(s): Peter J. Davis, Franklyn P. Cladis, Etsuro K. Motoyama, Smith's Anesthesia for Infants and Children (Eighth Edition), Mosby, 2011, Pages 971-1002, ISBN 9780323066129, https://doi.org/10.1016/B978-0-323-06612-9.00030-4.
41. Trine Lembrecht Jørgensen, Jesper Hallas, Lotte Holm Land, Jørn Herrstedt, Comorbidity and polypharmacy in elderly cancer patients: The significance on treatment outcome and tolerance, Journal of Geriatric Oncology, Volume 1, Issue 2, 2010, Pages 87-102, ISSN 1879-4068, https://doi.org/10.1016/j.jgo.2010.06.003.
42. Yehya N, Harhay MO, Curley MAQ, Schoenfeld DA, Reeder RW. Reappraisal of Ventilator-Free Days in Critical Care Research. Am J Respir Crit Care Med. 2019 Oct 1;200(7):828-836. doi:10.1164/rccm.201810-2050CP. PMID: 31034248; PMCID: PMC6812447.
43. Arrighi HM, Hertz-Picciotto I. The evolving concept of the healthy worker survivor effect. Epidemiology. 1994 Mar;5(2):189-96. doi: 10.1097/00001648-199403000-00009. PMID: 8172994.