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ACCELERATED BIOLOGICAL AGING AMONG MALE U.S. VETERANS: A NATIONAL SURVEY ANALYSIS

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Abstract:

Introduction: *Biomarkers of cellular aging (e.g., telomere length) reflect biological aging and are influenced by environmental and social factors. Veterans often face health disparities, and understanding telomere dynamics could inform personalized approaches to improve their health outcomes.*
Methods: *Using data from the National Health and Nutrition Examination Survey, we analyzed telomere length among 929 U.S. male veterans aged 20-84 years, examining associations with socioeconomic status, health conditions, and lifestyle factors through survey-weighted linear regression models.*
Results: *Veterans exhibited significantly shorter telomeres compared to civilians, with an average reduction of approximately 229.61 base pairs (bp) (p < .0001). Factors such as poverty, obesity, and COPD were independently associated with greater telomere shortening; for example, veterans living below the poverty line had about 261 bp less telomere length, and those with COPD showed a reduction of approximately 182 bp. Obese veterans had about 152 bp shorter telomeres, and the combination of poverty and obesity resulted in a cumulative shortening of approximately 424 bp, indicating a synergistic effect on cellular aging. These associations persisted after adjusting for age and other confounders, emphasizing the impact of socioeconomic and health-related factors on biological aging among veterans.*
Conclusion: *These findings are associated with shorter telomeres and may inform risk stratification and targeted prevention.*

Keywords: *telomeres, epigenetics, veterans, biological aging, health disparities, modifiable risk factors, social determinants of health.*

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INTRODUCTION

Epigenetics is the study of heritable changes in gene function and expression that do not involve changes in DNA sequence (1,2). These changes to gene expression can occur through environmental effects or physiological states and are mediated through various epigenetic mechanisms including DNA methylation, histone modification, or telomere regulation (1). Specifically, literature has noted the role of telomere shortening in several chronic diseases such as traumatic stress, diabetes mellitus, Alzheimer's disease, cardiovascular disease, liver cirrhosis, hypertension, and cancer (1,3–5). Fundamental in maintaining genomic stability and structural integrity, telomeres are specialized ribonucleoprotein structures located at the ends of chromosomes and consist of a repetitive DNA sequence 5'–$(TTAGGG)_n$–3' (in mammals) and shelterin protein complexes (1,4–6). Key functions of telomeres include ensuring each cell cycle has proper completion of genome replication, regulating gene expression and cellular signaling, and triggering replicative senescence or apoptosis in cultured cells, (1,5). Research has shown that nearly all human tissues undergo telomere shortening during the natural aging process (1,5). Telomere lengths are partly genetically inherited; however, environmental factors such as smoking, pollution, unhealthy lifestyle, etc. are known to negatively impact telomere length (5,6). Few studies, however, have evaluated telomere shortening among U.S. veterans, despite the population sharing a disproportionately higher burden of chronic diseases and intermediate risk factors, such as obesity.

Military service members are often required to complete a medical screening process and uphold physical conditioning standards, and as such are often healthier than the general population (7). However, for the 21 million individuals who have transitioned out of the military and are now veterans, their health is often assessed as equivalent or worse than the health of their civilian counterparts (7). It is not uncommon for veterans to experience health disparities typically explained by poor health behaviors such as tobacco and alcohol use, physical inactivity, or poor nutrition (7). Veterans are more likely to use tobacco products, misuse alcohol, and have higher waist circumferences than civilians within the general population (7). No longer being held accountable for meeting physical fitness standards or encountering barriers such as physical disabilities, veterans are more apt to experience a surge in weight gain during the transition period out of military service (8,9). Current literature notes that over three-fourths of the veteran population is overweight or obese as compared to two-thirds of the general population (9). Understanding these epigenetic mechanisms, particularly telomere dynamics, offers potential for integrating personalized approaches in healthcare. Leveraging epigenetic markers such as telomere length could help inform precision medicine strategies aimed at tailored prevention and intervention efforts for veterans, addressing individual biological and environmental factors that influence health outcomes.

METHODS

Data Source

The National Health and Nutrition Examination Survey (NHANES) was used in this analysis as it consisted of telomere information and have been previously used in other studies (10,11). The study population consisted of male veterans. Veteran status was selected based on those who answered yes to the question "Did you ever serve in the Armed Forces of the United States?" Since the telomere length assay was given to those aged 20 years and older and NHANES masks those aged 85 or older, our study population's age was thus restricted to those between ages 20 to 84 years. Respondents that answered yes to "Have you ever been told by a doctor or other health professional that you had cancer or a malignancy of any kind?" were excluded from the analysis as cancer therapeutic treatments can lead to altered telomere length (12). As such, the final resulting sample size for this study was 929 male veterans representing an annual population estimate of 10,051,182.

Variables

The outcome variable of interest was telomere length in base pairs (bp), calculated from NHANES-provided telomere mean T/S ratio with the equation bp=$[3{,}274 + 2{,}413\left(\frac{T}{S}\right)]$ (13). Given the substantial correlation of age and telomere length, we used age-adjusted telomere length as our outcome of interest. Age-adjusted telomere length was created using the residuals from a survey-weighted regression of age predicting telomere length.

Independent variables utilized in this study were: race/ethnicity (non-Hispanic Black, non-Hispanic White, and other) poverty level based on family income to federal poverty threshold (less than 100%, at or above 100%), smoking status defined as smoked at least 100 cigarettes in life time (yes, no), and average number of alcohol drinks per day in past 12 months. In addition, we utilized presence or absence of cardiovascular diseases, chronic obstructive pulmonary disease, and obesity (assessed through NHANES-provided body mass index variable).

Analysis

All analyses utilized the appropriate survey weights for participants selected to complete the Mobile Examination Clinic (MEC) module, including the four-year MEC examination weight (WTMEC4YR), which is used for combined NHANES cycles. SAS 9.4 (SAS Institute Inc.; Cary, NC) was utilized for all statistical analyses, with alpha less than .05 used to denote significance.

A survey-weighted linear regression was run with least square means to assess differences in mean age-adjusted telomere length between veterans and civilians. Univariate analysis of study population characteristics utilized survey-weighted relative frequencies and means, while bivariate and multivariable associations between age-adjusted telomere length and study variables were evaluated with survey-weighted linear regression. Relevant interactions were assessed for least squares mean differences with a Tukey-Kramer post-hoc adjustment.

RESULTS

A significant association was found between veteran status and both age-adjusted and unadjusted telomere length. For example, veteran status was associated with 229.61 less bp (95% CI: 186.07-273.14; $p < .0001$) of telomere length, compared to civilians, on average. Likewise, veteran status was also associated with 57.27 less bp (95% CI: 16.32-90.23; $p < .01$) of age-adjusted telomere length, as compared to civilians, on average.

Table 1 displays the characteristics of our study population: U.S. Veterans (male). Mean age of the study population was 53.98 years (95% CI: 52.81-55.16), and mean age-adjusted telomere length was 5647.16 bp for the study population. The highest proportion of the population were also non-Hispanic Whites (84.63%), living at or above the 100% of the income to poverty ratio (93.39%), and were considered as smokers (67.29%). The study population also reported drinking an average of 1.74 alcohol beverages per day in the past 12 months. In addition, prevalence of cardiovascular disease (CVD), chronic obstructive pulmonary disease (COPD), and obesity in the population were reported at 13.57%, 6.32%, and 31.26%, respectively.

Table 2 shows the relationship between each population characteristics and age-adjusted mean telomere length. We noted significant association between poverty level and age-adjusted telomere length, with a lower length noted among those who lived at less than 100% of the income to poverty ratio, as well as those who reported COPD and were obese.

Table 3 highlights the results of multiple linear regression analyses. Significant associations were noted among several characteristics and age-adjusted telomere length. U.S. male veterans residing below the 100% income to poverty threshold reported approximately 261 less bp in telomere length. In addition, those with COPD reported 182 less bp compared to their counterparts with no COPD, while participants who were obese also also had approximately 152 less bp of telomere length as compared to those who were not obese.

As shown in Table 4, interaction assessment demonstrated that those who were living at less than 100% of the poverty level and were obese had approximately 424 less bp of age-adjusted telomere length as compared to those at the same poverty level but not obese.

DISCUSSION

This study provides important insights into the relationship between socioeconomic factors, health conditions, and telomere length, a marker for accelerated aging, among U.S. male veterans. Our findings demonstrate that veterans exhibit significantly shorter telomeres in comparison to civilians, with an average reduction of approximately 229.61 bp, and that this shortening is strongly associated with modifiable determinants such as poverty, obesity, and COPD. This association persisted after adjusting for age, suggesting that factors beyond chronological aging contribute to telomere attrition in this population. These results underscore the potential role of chronic stressors and modifiable health and social factors in influencing biological aging processes at the cellular level.

For example, Barrett and colleagues note that psychological stress may lead to long-lasting changes in human monocytes, making them more prone to producing inflammation. These immune cells undergo gene expression and chromatin modifications that enhance their responsiveness to inflammatory stimuli. Such stress-induced reprogramming of monocytes may further explain the increased risk of inflammatory diseases associated with chronic psychological stress (14). Likewise, among middle-aged adults in the United States, markers for biological aging was found to be associated with poverty (15).

Interestingly, in our study, we noted that U.S. Veterans had a heightened biological acceleration as compared to their civilian counterparts, noting putative role of unique stressors common to the military experience. For example, research has highlighted that barriers to successful civilian adjustment for veterans on the U.S.–Mexico border include ongoing military-influenced mindsets, strained family relationships, experiences of victimization and discrimination, and limited access to mental health care and opportunities (16); cumulatively noting an unique set of barriers to well-being in the population. Our results on the accelerated biological aging among such a population could thus be attributable to such experiences.

Moreover, our results highlight the significant role of health conditions such as COPD and obesity on telomere length. Veterans with COPD had approximately 182 bp shorter telomeres. Similarly, obesity was associated with a reduction of about 152 bp. Together, such results putatively emphasize the role of inflammation and metabolic stress in telomere dynamics. Further, the interaction analysis further revealed that obesity exacerbates this association where veterans at or below the poverty line who are also obese experienced the greatest telomere shortening, with a reduction of approximately 424 bp. These findings suggest a synergistic effect where socioeconomic disadvantages coupled with obesity accelerate cellular aging, possibly via pathways involving chronic inflammation and metabolic dysregulation (17).

Interestingly, while race/ethnicity and smoking status did not show statistically significant associations with telomere length in multivariable models, it is important to consider that these factors may have complex interactions or cumulative effects not fully captured in this analysis. The high prevalence of smoking (67%) in our sample underscores its potential long-term impact on telomere attrition, although further research with larger samples and longitudinal data is necessary to elucidate these relationships.

The cross-sectional nature of our study limits causal inferences; however, the significant associations observed underscore the importance of addressing social determinants of health and modifiable health behaviors among veterans. Interventions aimed at reducing obesity and managing chronic conditions could potentially mitigate telomere shortening and its downstream health consequences. Additionally, these findings advocate for enhanced screening and targeted support programs to address socioeconomic disadvantages in veteran populations, which may serve as upstream factors influencing biological aging.

CONCLUSION

Together, our study highlights that U.S. male veterans experience greater telomere shortening compared to civilians, and that socioeconomic and health disparities, particularly modifiable factors such as poverty, obesity, and COPD, significantly contribute to these differences rather than reflecting inherent biological age. These insights reinforce the importance of addressing these modifiable determinants within a health administration framework and may have implications for precision medicine (18), while recognizing that further research is needed to establish causal outcomes. Importantly, telomere length should be considered a marker of modifiable risk rather than an inherent trait, and any operational use of such markers should be guided by ethical principles to prevent stigmatization.

Nevertheless, recognizing biological aging markers, such as telomere length, alongside socioeconomic and health factors, can help tailor interventions and healthcare strategies to individual veteran needs, ultimately improving outcomes. Personalized approaches that focus on both modifiable biological and social determinants could enhance disease prevention, optimize resource allocation, and foster equitable access to targeted treatments, thereby advancing veteran healthcare delivery in a responsible and effective manner.

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Table 1. Study population characteristics; n = 929; N = 10,051,182	
Age-adjusted telomere length (in bp), mean (SE)	5647.16 (29.23)
Race/ethnicity, %	
Non-Hispanic Black	8.01
Non-Hispanic White	84.63
Other	7.36
Poverty level, %	
Less than 100%	6.61
At or above 100%	93.39
Smoked at least 100 cigarettes in life, %	
No	32.71
Yes	67.29
Average number of alcohol drinks per day in past 12 months, mean (SE)	1.74 (0.02)
CVD, %	
No	86.43
Yes	13.57
COPD, %	
No	93.68
Yes	6.32
Obese, %	
No	68.74
Yes	31.26
BP = base pairs, SE = standard error, CVD = cardiovascular disease, COPD = chronic obstructive pulmonary disease	

Table 2. Mean age-adjusted telomere length (in bp) by study population characteristics.	
	Telomere length bp (95% CI)
Race/ethnicity	
Non-Hispanic Black	5684.94 (5576.88, 5792.99)
Non-Hispanic White	5643.69 (5577.18, 5710.20)
Other	5645.91 (5495.65, 5796.17)
Poverty level	*
At or above 100%	5656.53 (5596.74, 5716.31)
Less than 100%	5477.04 (5340.82, 5613.25)
Smoked at least 100 cigarettes in life	
Yes	5647.48 (5577.99, 5716.97)
No	5646.12 (5577.21, 5715.04)
Average number of alcohol drinks per day in past 12 months +	5632.92 (5554.37, 5711.46)
CVD	
Yes	5610.16 (5488.80, 5731.52)
No	5654.29 (5600.08, 5708.50)
COPD	*
Yes	5519.11 (5385.64, 5652.58)
No	5654.88 (5595.73, 5714.03)
Obese	*
Yes	5589.58 (5519.48, 5659.67)
No	5670.44 (5599.46, 5741.41)

bp = base pairs, CI = confidence interval, CVD = cardiovascular disease, COPD = chronic obstructive pulmonary disease
+Predicted mean age-adjusted telomere length at average value of alcohol use
* $p < .05$

Table 3. Results of survey weighted multiple linear regression.	
	Telomere length bp (95% CI)
Race/ethnicity	
Non-Hispanic White	Ref.
Non-Hispanic Black	78.23 (-89.00, 245.47)
Other	70.38 (-129.93, 270.68)
Poverty level	
At or above 100%	Ref.
Less than 100%	-260.54 (-392.56, -128.51)*
Smoked at least 100 cigarettes in life	
No	Ref.
Yes	-40.05 (-149.11, 69.00)
Average # of alcohol drinks per day in past 12 months	3.24 (-3.19, 9.67)
CVD	
No	Ref.
Yes	74.87 (-37.98, 187.72)
COPD	
No	Ref.
Yes	-182.16 (-347.52, -16.79)*
Obese	
No	Ref.
Yes	-151.77 (-261.00, -42.54)*

bp = base pairs, CI = confidence interval, CVD = cardiovascular disease, COPD = chronic obstructive pulmonary disease
* $p < .05$

Table 4. Least squares mean differences for interaction between poverty and obesity

	Obese vs. Not Obese Least Squares Mean Difference (95% CI)
Less than 100%	-424.24 (-728.66, -119.82)*
At or above 100%	-131.06 (-279.69, 17.57)

* $p < .05$