Longer term All-Cause and Cardiovascular Mortality with Intensive Blood Pressure Control: A Secondary Analysis of SPRINT

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# ABSTRACT

**IMPORTANCE**. The Systolic Blood Pressure Intervention Trial (SPRINT) showed that intensive treatment, defined by a systolic blood pressure (SBP) goal of <120mmHg, reduced the risk of cardiovascular and all-cause mortality. However, the legacy effect of intensive treatment on mortality, defined as the persistence of benefit after stopping intensive treatment, is unknown.

**OBJECTIVE**. To evaluate the legacy effect of receiving intensive treatment during the SPRINT trial with all-cause and cardiovascular mortality up to ten years post-randomization.

**DESIGN, SETTING, AND PARTICIPANTS**. Randomized clinical trial of 9361 patients aged 50 years or older with hypertension and increased cardiovascular risk, but without diabetes or history of stroke. Randomization began on November 8, 2010, the trial intervention ended on August 20, 2015, and observational trial follow-up visits occurred through July 2016.

**INTERVENTIONS**. Randomization to SBP goal of <120mmHg (intensive, N=4678) versus <140mmHg (standard, N=4683).

**MAIN OUTCOMES AND MEASURES**. Extended trial follow-up assessed mortality via the US National Death Index, beginning in 2016 through December 31st, 2020. In a subset of 2944 trial participants, outpatient SBP levels measured in routine clinical practice after the trial were examined.

**RESULTS**. Among 9361 randomized participants, the mean (standard deviation) age was 67.9 (9.4) years and 35.6% were women. Over the median intervention phase of 3.3 years, intensive treatment was beneficial for both cardiovascular mortality (Hazard Ratio [HR] = 0.66, 95% confidence interval [CI] 0.49 to 0.89) and all-cause mortality (HR = 0.83, 95% CI 0.68 to 1.01). However, at the median total follow-up of 8.8 years, there was no longer evidence of benefit for cardiovascular mortality (HR = 1.02, 95% CI 0.84 to 1.24) or all-cause mortality (HR = 1.08, 95% CI 0.94 to 1.23). The estimated mean (95% CI) outpatient SBP among participants randomized to intensive treatment increased from 132.8 (132.0, 133.7) at five years to 140.4 (137.8, 143.0) ten years post-randomization.

**CONCLUSIONS AND RELEVANCE**. The beneficial effect of intensive treatment on cardiovascular and all-cause mortality did not persist after the trial was stopped. Given increasing SBP levels in participants randomized to intensive treatment following the trial, these results highlight the importance of consistent long-term management of hypertension.

# INTRODUCTION

Hypertension is the leading modifiable risk factor for cardiovascular disease (CVD).1 The Systolic Blood Pressure Intervention Trial (SPRINT) showed that intensive treatment, defined by a SBP target < 120 mm Hg, reduced the risk for cardiovascular and all-cause mortality.2 Because a clear benefit was evident for intensive treatment after a median follow-up of 3.3 years, SPRINT was stopped early. However, the persistence of benefit after the trial was stopped (i.e., “legacy” effect) of intensive treatment on cardiovascular and all-cause mortality has not been evaluated.3

The objective of the current study was to evaluate the effect of stopping intensive treatment as specified by the SPRINT trial protocol by analyzing post-trial all-cause and cardiovascular mortality. A secondary objective was to examine SBP following the discontinuation of the trial intervention. To accomplish these objectives, we linked participants to the National Death Index (NDI) from 2016 through 2020 and extracted longitudinal outpatient measurements of SBP from 20xx to 2020 available in the electronic health record (EHR) for a subset of trial participants.

# METHODS

**Trial Design**: The design and methods of SPRINT have been published previously.2,4 Briefly, it was a multicenter randomized clinical trial that compared two strategies for managing SBP in older adults with hypertension who were at increased risk of CVD. Participants were aged 50 years or older and had an SBP between 130 and 180 mm Hg at the screening visit, depending on the number of anti-hypertensive agents prescribed. Participants were considered to have an increased cardiovascular risk if they had clinical or subclinical cardiovascular disease, chronic kidney disease (CKD), or a Framingham Risk Score of 15% or greater or if they were aged 75 years or older. Individuals residing in a nursing home, persons with a diagnosis of dementia (based on medical record review), and those treated with medications primarily used for dementia therapy were excluded, as were persons with prevalent diabetes mellitus, history of stroke, proteinuria > 1 gram per day, or polycystic kidney disease. Individuals at 102 sites in the United States and Puerto Rico were randomized (1:1) to a SBP goal of less than 120 mm Hg (intensive treatment group, n = 4678) or a goal of less than 140 mm Hg (standard treatment group, n = 4683), using random permuted blocks with the randomization stratified by clinic site. Randomization began on November 8, 2010 and ended in March 2013. On August 20, 2015, the SPRINT trial prematurely concluded due to the clear benefit of intensive treatment. As trial follow-up visits and provision of antihypertensive medication continued through July 2016,2 the current study considers a trial phase spanning from November 8, 2010 through July 2016 and an observational phase spanning from August 2017 through December, 2020 (**eFigure 1**). The study was approved by the institutional review board at each participating site, and each participant provided written informed consent. The study is registered at ClinicalTrials.gov (NCT01206062).

**Baseline Study Measurements**: Sociodemographic data were collected at baseline, with race or ethnicity information collected via self-report. The estimated glomerular filtration rate (eGFR) was calculated by the race-free 2021 CKD-EPI creatinine equation.5 Cognitive function was assessed using the Montreal Cognitive Assessment (MoCA).6 Lower cognitive function was defined as scoring at or below the estimated age and education-specific normative 10th percentile from the Irish Longitudinal Study of Aging,7 after adding three points to the scores of non-White participants.8 We defined frailty status at baseline using a 36-item Frailty Index (FI) based upon the model of deficit accumulation.9 The FI is calculated as the sum of the score for each deficit divided by the total number of nonmissing items. We categorized frailty status as fit (FI ≤ 0.10), less fit (0.10 < FI ≤ 0.21), or frail (FI > 0.21).

**National Death Index Linkage**: Outcomes of interest included all-cause and cardiovascular mortality. Methods of ascertainment and adjudication through the course of trial follow-up have been previously described.2 In the final report of the SPRINT trial, mortality was ascertained through a US National Death Index (NDI) search completed in December 2016.2 For the current analysis, we completed an NDI search including deaths through 2020. As the NDI is continuously updated, the current analysis includes some deaths in 2016 that were not identified at the time of the final SPRINT report. Possible matches were identified according to NDI guidelines.10 Deaths were treated as confirmed if they were a Class 1 match, or a Class 2, 3, or 4 match with a probabilistic score above cutoffs recommended by the NDI.10 Deaths ascertained in 2020 were based on the NDI preliminary data release. CVD mortality for NDI-based follow-up used the NDI Plus System, which automatically identifies underlying causes of death from death certificates, including conversion to ICD-10 codes. We defined CVD mortality as any death containing the ICD-10 codes of I00 to I99.11

**EHR Ancillary Study**: Methods for the linkage of participants to their medical record number and the extraction of vital sign data have been previously described.12 We identified 3074 participants with 3 or more outpatient and trial BP measurements. After excluding 130 participants without EHR data following July 2016 (i.e., conclusion of the trial phase), a total of 2944 patients were included for the ancillary BP analysis. Because encounter type information was inconsistently available (i.e. outpatient, inpatient, observation, etc.), we defined a BP measurement as outpatient if there was not a BP measurement on the preceding or following day, and if there were 2 or less BP measurements on a particular day. We averaged outpatient EHR BP readings when there were 2 on the same day.

**Statistical Analysis**: Given the *a priori* expectation that treatment group differences may not be constant as a function of follow-up time (i.e. the proportional hazards assumption was likely to be invalid), we modeled treatment group differences as a function of time using two approaches. The first approach split each participant’s follow-up time into non-overlapping trial and observational phases, and estimated regression coefficients for intensive treatment separately during each phase.13 The second approach estimated a regression coefficient for intensive treatment as a continuous function of time since randomization.14,15 All analyses accounted for correlation within study sites,16 and analyses of cardiovascular mortality accounted for the competing risk of non-cardiovascular mortality.17

We examined the trajectory of SBP following the conclusion of the trial using outpatient SBPs extracted from the EHR. Mean between-group differences in outpatient SBP were estimated using linear mixed models. Models included random effects for participant and clinic site and an interaction between treatment group and time since randomization, which was modeled using B-splines. All analyses were performed using SAS version 9.4 (SAS Institute Inc, Cary, NC) and R version 4.1.2 (R Project for Statistical Computing [<http://www.r-project.org>]) with multiple auxiliary R packages.18–23 All hypothesis tests were 2-sided, and P values less than 0.05 were considered statistically significant. No adjustments for multiple comparisons were made.

# RESULTS

***Study Participants***. A total of 9361 participants were randomized between November 2010 and March 2013. The mean (standard deviation [SD]) age was 67.9 (9.4) years, with 28.2% of participants aged 75 years or older (**eTable 1**). Participants were 35.6% female and 31.5% black. The mean (SD) SBP at baseline was 139.7 (15.6) and 27.0% of participants MoCA scores were below the 10th percentile. Compared to participants not included in the ancillary EHR study, participants included were more likely to be male, were older, had lower SBP and higher scores on the MoCA, and had a higher prevalence of CKD.

***All-cause Mortality***. In both treatment groups, the total median follow-up time was 8.8 years. A total of 818 and 826 deaths occurred among participants randomized to intensive and standard treatment, respectively (**eTable 2**). The hazard ratio (HR) for all-cause mortality comparing intensive to standard treatment was 0.83 (95% confidence interval [CI] 0.68, 1.01) during the trial phase, and 1.08 (95% CI 0.94, 1.23) during the observational phase. The continuous time-dependent effect of intensive versus standard treatment indicated a benefit for all-cause mortality from 1.03 to 2.8 years from randomization, and was attenuated throughout the remainder of the observational phase (**Figure 1**). In subgroups based on age, sex, race, CKD, cognitive function, and frailty status, there was no evidence that intensive treatment during the trial phase produced benefit for all-cause mortality during the observational phase of follow-up (**Figure 2**).

***Cardiovascular Mortality***. A total of 248 and 273 CVD deaths occurred among participants randomized to intensive and standard treatment, respectively (**eTable 3**). The HR for CVD mortality among participants randomized to intensive versus standard treatment was 0.66 (95% CI 0.49, 0.89) during the trial phase and 1.02 (95% CI 0.84, 1.24) during the observational phase. The time-dependent effect of intensive versus standard treatment indicated a benefit for CVD mortality from 2.3 to 5.6 years from randomization, and was attenuated throughout the remainder of the observational phase (**Figure 3**). Adults randomized to intensive treatment who were <75 years of age, men, non-black, without CKD, or with cognitive function >10th percentile had lower CVD mortality risk during the trial phase compared to their counterparts randomized to standard treatment, but there was no evidence that intensive treatment during the trial phase produced benefit for CVD mortality during the observational phase (**Figure 4**).

***Blood Pressure***. Amongst a subset of 2944 trial participants, the median number of outpatient BP measurements extracted from the EHR during the observational phase of follow-up was 20 (IQR 10 to 34). The estimated mean (95% CI) SBP among participants randomized to intensive treatment was 132.8 (132.0, 133.7) at 5 years and 140.4 (137.8, 143.0) at 10 years post-randomization (**Figure 5**). For participants randomized to standard treatment, mean (95% CI) SBP was estimated to be 138.8 (137.9, 139.6) at 5 years and 140.2 (137.7, 142.6) post-randomization. The between-group difference in mean SBP levels (intensive minus standard) was 5.9 (5.2, 6.7) mm Hg at 5 years post-randomization and was reduced to 5.9 (5.2, 6.7) at 10 years post-randomization (**eFigure 2**).

# DISCUSSION

The current study analyzed all-cause and CVD-mortality among SPRINT participants up to 10 years following randomization, finding that the benefits associated with intensive treatment quickly attenuated as SBP levels increased after the trial intervention was discontinued. Time-varying estimates of the benefit of intensive treatment for all-cause mortality were attenuated at 2.8 years while the benefit for CVD-mortality was attenuated at 5.6 years post-randomization. Findings from our ancillary study of outpatient SBP measured in routine clinical practice indicated that the difference in SBP between treatment groups diminished over time, with no detectable difference in SBP approximately 9 years after randomization. These results in combination with the primary findings of SPRINT indicate that the beneficial effect of intensive treatment among adults with hypertension appears to diminish if BP control is not sustained.

The Strategy of Blood Pressure Intervention in the Elderly Hypertensive Patients (STEP) trial enrolled 8511 Chinese patients 60 to 80 years of age with hypertension and randomized patients to a SBP target of 110 to less than 130 mm Hg (intensive treatment) or a target of 130 to less than 150 mm Hg (standard treatment).24 STEP found a HR of 0.72 (95% CI 0.39, 1.32) with intensive versus standard treatment for CVD mortality after a median follow-up of 3.34 years, but did not find evidence of a benefit for all-cause mortality. In the current study of SPRINT participants, the protective effect of intensive treatment for all-cause mortality was attenuated several years before the protective effect for CVD. These results in combination with findings from the STEP trial suggest weaker evidence for reduced all-cause versus CVD mortality risk with intensive BP control.

Meta analyses of randomized trials have shown that pharmacological blood pressure (BP) lowering reduces the risk of major CVD events across the spectrum of initial BP.25,26

Previous studies have found rising BP levels among US adults during the time period of the current study. General population studies of adults living in the US with hypertension found that the prevalence of uncontrolled BP (SBP ≥ 140 mm Hg or DBP ≥ 90 mm Hg) increased from 2013 to 2017.27 In addition, an analysis of data from 464,585 adults enrolled in a Quest Diagnostics wellness program found SBP was 1 mm Hg and 3 mm Hg higher, depending on age group and sex, in April through December of 2020 versus their corresponding values throughout 2019.28 The current study shows that even for adults who have maintained intense SBP control for 3 years, increasing SBP levels can quickly diminish the protective effect. Combined with previous findings on rising BP levels among US adults, data from the current study emphasize the need for implementation of population- and community-level strategies to improve BP control in the US.

In October 2020, the US Surgeon General published a call to action to control hypertension.29 Evidenced-based strategies to improve BP control addressed in the call to action include implementing treatment protocols, using integrated care teams, providing clinicians feedback on their performance, and promoting shared patient-provider management with self-measured BP monitoring. During the SPRINT trial, participants received team-based care consistent with strategies outlined in the 2020 call to action and providers received real time feedback on individual and aggregate participant blood pressure control. After the trial phase, when these protocols were no longer followed by the primary care providers, the incidence of all-cause mortality approximately doubled in both treatment groups. These data emphasize the benefit that can be realized by implementing the goals and strategies of the 2020 US Surgeon General’s call to action. Future research should continue to evaluate strategies for obtaining consistent BP control in clinical settings to reduce the burden of CVD, which remains the leading cause of death for US adults.

This study has several limitations. First, while we restricted analyses to high quality NDI matches, misclassification in linking participants to the NDI is possible. Second, while several studies have shown reasonable performance of using NDI diagnosis codes for defining CVD mortality,11 it is not as robust as the adjudication process used in the primary follow-up for the trial. Third, information about SBP control after the trial was limited to routine outpatient SBP values extracted from the EHR, which are known to poorly reflect the standardized BP measurement process used during the SPRINT trial.12 While this prohibits definite conclusions about the absolute level of BP in both treatment groups, as well as pin-pointing when the between-group difference may have completely attenuated, the observation of steadily increasing SBP for participants in the intensive treatment and relatively stable SBP in the standard treatment group following the trial is likely still valid.

In conclusion, while intensive treatment produced beneficial effects on mortality during the trial, there was no evidence that this produced sustained benefits on cardiovascular and all-cause mortality subsequent to discontinuing the intervention protocol. Given steadily increasing mean SBP levels in participants randomized to intensive treatment after the trial, these results demonstrate that maintaining more intensive BP targets throughout adulthood will likely be essential for long-term CVD risk management.

# REFERENCES

1. Roth GA, Mensah GA, Johnson CO, et al. Global Burden of Cardiovascular Diseases and Risk Factors, 1990-2019: Update From the GBD 2019 Study. *J Am Coll Cardiol*. 2020;76(25):2982-3021.

2. SPRINT Research Group, Lewis CE, Fine LJ, et al. Final Report of a Trial of Intensive versus Standard Blood-Pressure Control. *N Engl J Med*. 2021;384(20):1921-1930.

3. Wander GS, Bansal M. Legacy effect in medicine—the expanding horizon! *Indian Heart Journal*. 2018;70(6):769-771. doi:[10.1016/j.ihj.2018.12.001](https://doi.org/10.1016/j.ihj.2018.12.001)

4. Ambrosius WT, Sink KM, Foy CG, et al. The design and rationale of a multicenter clinical trial comparing two strategies for control of systolic blood pressure: The Systolic Blood Pressure Intervention Trial (SPRINT). *Clinical Trials*. 2014;11(5):532-546. doi:[10.1177/1740774514537404](https://doi.org/10.1177/1740774514537404)

5. Inker LA, Eneanya ND, Coresh J, et al. New Creatinine- and Cystatin C–Based Equations to Estimate GFR without Race. *New England Journal of Medicine*. 2021;385(19):1737-1749. doi:[10.1056/NEJMoa2102953](https://doi.org/10.1056/NEJMoa2102953)

6. Nasreddine ZS, Phillips NA, Bédirian V, et al. The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool For Mild Cognitive Impairment. *Journal of the American Geriatrics Society*. 2005;53(4):695-699. doi:[10.1111/j.1532-5415.2005.53221.x](https://doi.org/10.1111/j.1532-5415.2005.53221.x)

7. Kenny RA, Coen RF, Frewen J, Donoghue OA, Cronin H, Savva GM. Normative values of cognitive and physical function in older adults: Findings from the Irish Longitudinal Study on Ageing. *Journal of the American Geriatrics Society*. 2013;61 Suppl 2:S279-290. doi:[10.1111/jgs.12195](https://doi.org/10.1111/jgs.12195)

8. Sachs BC, Chelune GJ, Rapp SR, et al. Robust demographically-adjusted normative data for the Montreal Cognitive Assessment (MoCA): Results from the systolic blood pressure intervention trial. *Clin Neuropsychol*. Published online September 2021:1-16.

9. Pajewski NM, Williamson JD, Applegate WB, et al. Characterizing Frailty Status in the Systolic Blood Pressure Intervention Trial. *The Journals of Gerontology Series A, Biological Sciences and Medical Sciences*. 2016;71(5):649-655. doi:[10.1093/gerona/glv228](https://doi.org/10.1093/gerona/glv228)

10. National Center for Health Statistics. *National Death Index User’s Guide*.; 2013. <https://www.cdc.gov/nchs/data/ndi/ndi_users_guide.pdf>

11. Olubowale OT, Safford MM, Brown TM, et al. Comparison of Expert Adjudicated Coronary Heart Disease and Cardiovascular Disease Mortality With the National Death Index: Results From the REasons for Geographic And Racial Differences in Stroke (REGARDS) Study. *J Am Heart Assoc*. 2017;6(5).

12. Drawz PE, Agarwal A, Dwyer JP, et al. Concordance Between Blood Pressure in the Systolic Blood Pressure Intervention Trial and in Routine Clinical Practice. *JAMA internal medicine*. 2020;180(12):1655-1663. doi:[10.1001/jamainternmed.2020.5028](https://doi.org/10.1001/jamainternmed.2020.5028)

13. Zhang Z, Reinikainen J, Adeleke KA, Pieterse ME, Groothuis-Oudshoorn CGM. Time-varying covariates and coefficients in Cox regression models. *Annals of Translational Medicine*. 2018;6(7):121. doi:[10.21037/atm.2018.02.12](https://doi.org/10.21037/atm.2018.02.12)

14. Martinussen T, Scheike TH. *Dynamic Regression Models for Survival Data*. Springer Science & Business Media; 2007.

15. Therneau T, Crowson C, Atkinson E. Using time dependent covariates and time dependent coefficients in the cox model. *Survival Vignettes*. 2017;2:3.

16. Lin DY, Wei LJ. The robust inference for the Cox proportional hazards model. *Journal of the American statistical Association*. 1989;84(408):1074-1078.

17. Scheike TH, Zhang MJ. Flexible competing risks regression modeling and goodness-of-fit. *Lifetime Data Analysis*. 2008;14(4):464-483. doi:[10.1007/s10985-008-9094-0](https://doi.org/10.1007/s10985-008-9094-0)

18. R Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing; 2020. <https://www.R-project.org/>

19. Jaeger B. *Table.glue: Make and Apply Customized Rounding Specifications for Tables*. <https://github.com/bcjaeger/table.glue>

20. Wickham H, Averick M, Bryan J, et al. Welcome to the tidyverse. *Journal of Open Source Software*. 2019;4(43):1686. doi:[10.21105/joss.01686](https://doi.org/10.21105/joss.01686)

21. Therneau TM. *A Package for Survival Analysis in R*.; 2021. <https://CRAN.R-project.org/package=survival>

22. Scheike TH, Zhang MJ. Analyzing competing risk data using the R timereg package. *Journal of Statistical Software*. 2011;38(2):1-15. <https://www.jstatsoft.org/v38/i02/>

23. Landau WM. The targets R package: A dynamic make-like function-oriented pipeline toolkit for reproducibility and high-performance computing. *Journal of Open Source Software*. 2021;6(57):2959. <https://doi.org/10.21105/joss.02959>

24. Zhang W, Zhang S, Deng Y, et al. Trial of Intensive Blood-Pressure Control in Older Patients with Hypertension. *N Engl J Med*. 2021;385(14):1268-1279.

25. Rahimi K, Bidel Z, Nazarzadeh M, et al. Age-stratified and blood-pressure-stratified effects of blood-pressure-lowering pharmacotherapy for the prevention of cardiovascular disease and death: An individual participant-level data meta-analysis. *The Lancet*. 2021;398(10305):1053-1064. doi:[10.1016/S0140-6736(21)01921-8](https://doi.org/10.1016/S0140-6736(21)01921-8)

26. Bundy JD, Li C, Stuchlik P, et al. Systolic blood pressure reduction and risk of cardiovascular disease and mortality: A systematic review and network meta-analysis. *JAMA cardiology*. 2017;2(7):775-781.

27. Muntner P, Hardy ST, Fine LJ, et al. Trends in Blood Pressure Control Among US Adults With Hypertension, 1999-2000 to 2017-2018. *JAMA*. 2020;324(12):1190-1200.

28. Laffin LJ, Kaufman HW, Chen Z, et al. Rise in Blood Pressure Observed Among US Adults During the COVID-19 Pandemic. *Circulation*. 2022;145(3):235-237. doi:[10.1161/CIRCULATIONAHA.121.057075](https://doi.org/10.1161/CIRCULATIONAHA.121.057075)

29. Substance Abuse and Mental Health Services Administration (US), Office of the Surgeon General (US). *The Surgeon General’s Call to Action to Control Hypertension*. US Department of Health; Human Services; 2020. Accessed November 24, 2021. <http://www.ncbi.nlm.nih.gov/books/NBK567645/>

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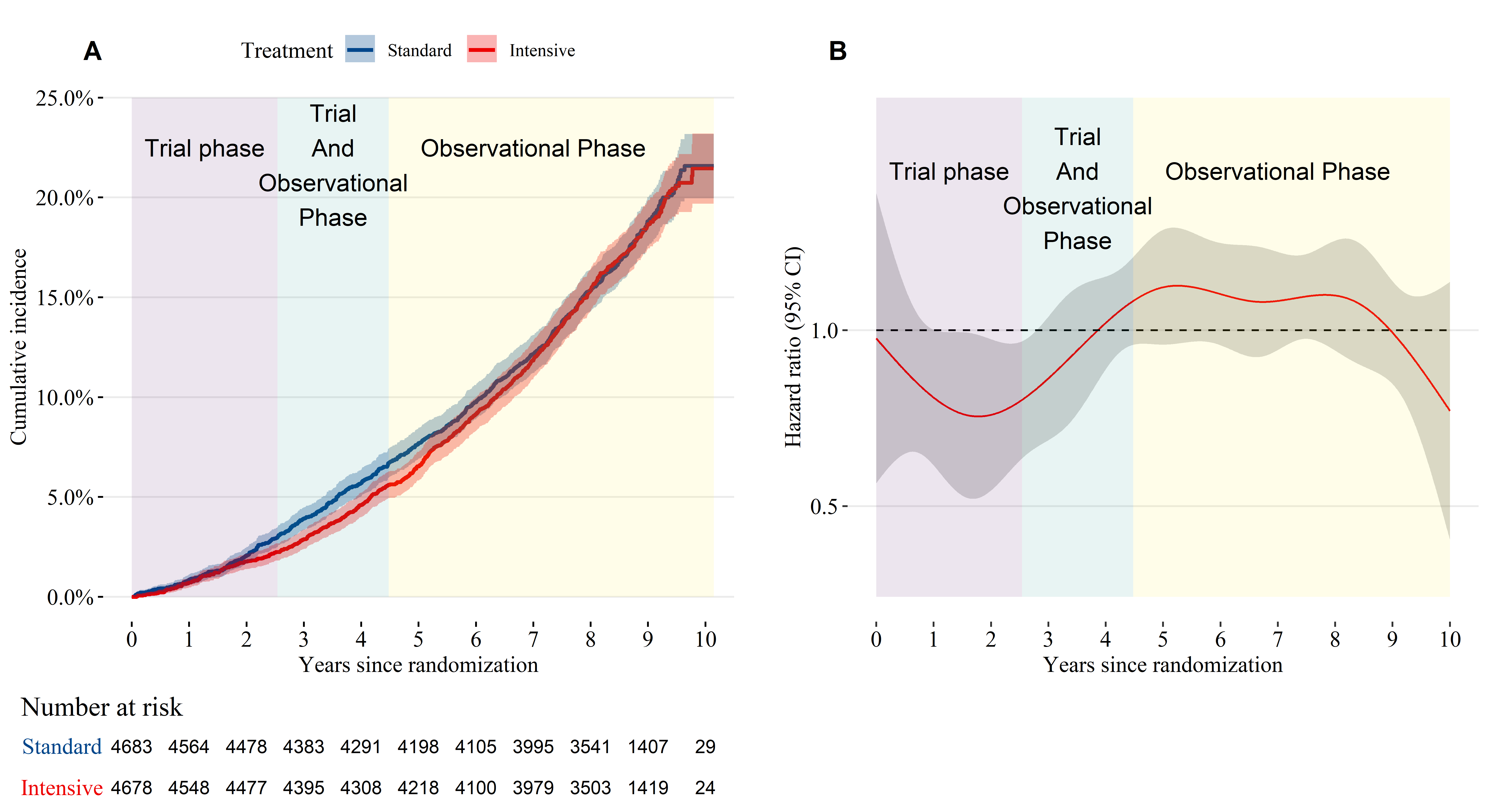
The views expressed in this paper are those of the authors and do not represent the official position of the National Institutes of Health (NIH), the National Heart, Lung, and Blood Institute, the Department of Veterans Affairs, or the U.S. Government, or the SPRINT Research Group. This paper was not reviewed by the SPRINT Publications and Presentations Committee. The authors also wish to acknowledge computing support provided the Veterans Affairs Informatics and Computing Infrastructure (VINCI).

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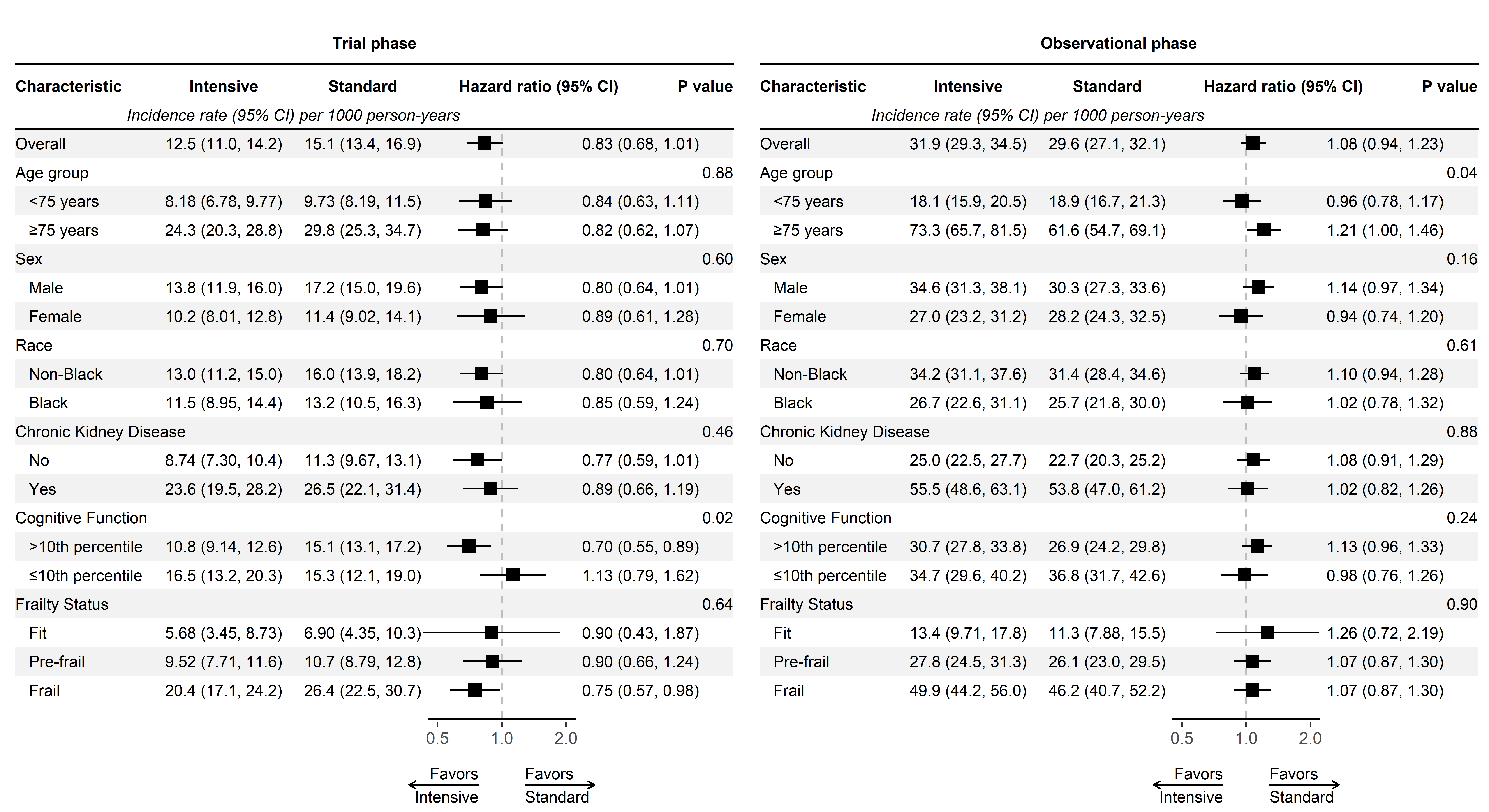
**Figure 1**: Incidence of All-Cause Mortality by Treatment Group.



1. Cumulative incidence of all-cause mortality by treatment group. (B) Time-dependent effect of randomization to intensive treatment for all-cause mortality.

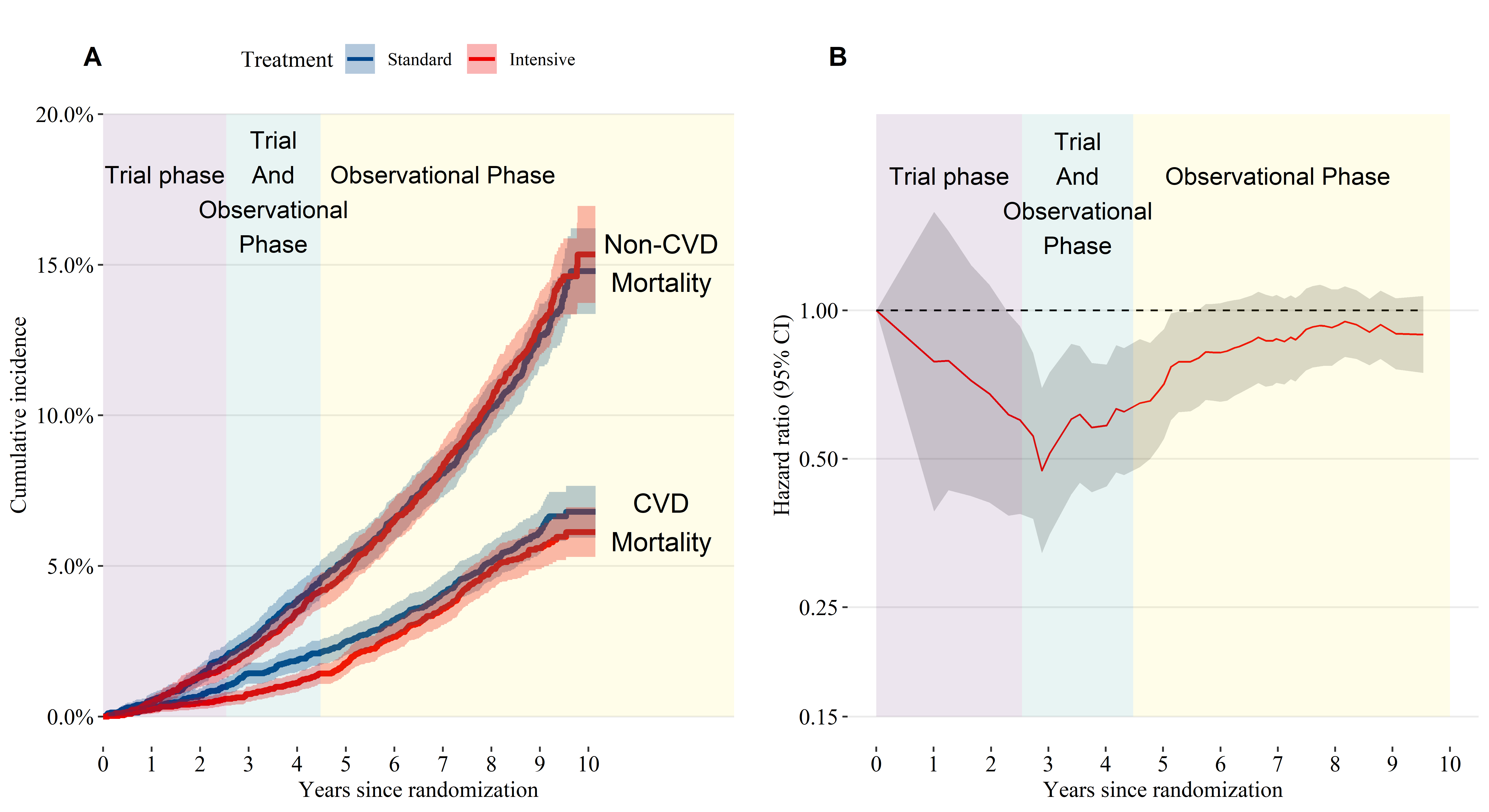
The trial phase and observational phase do not overlap for individual participants, but due to participants being randomized on different days, there is an overlap in the trial and observational phase for the population when time is measured relative to the date of randomization.

**Figure 2**: All-cause mortality hazard ratio subgroup analysis for participants randomized to intensive versus standard treatment.



P-values test for heterogeneity in the treatment effect among subgroups and were not adjusted for multiple testing.

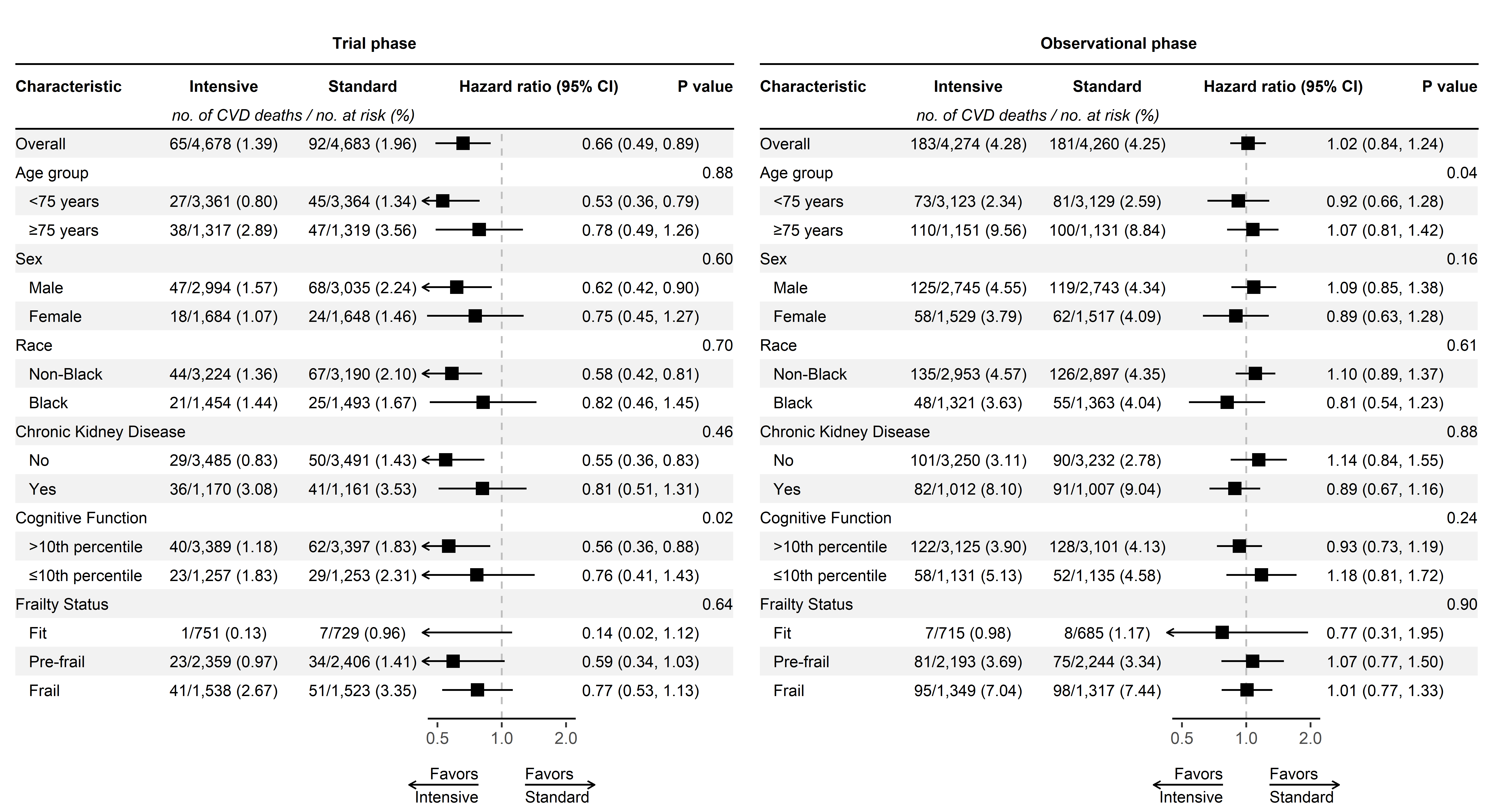
**Figure 3**: Incidence of cardiovascular versus non-cardiovascular mortality by treatment group.



1. Cumulative incidence of cardiovascular and non-cardiovascular mortality by treatment group. (B) Time-dependent effect of randomization to intensive treatment for cardiovascular mortality.

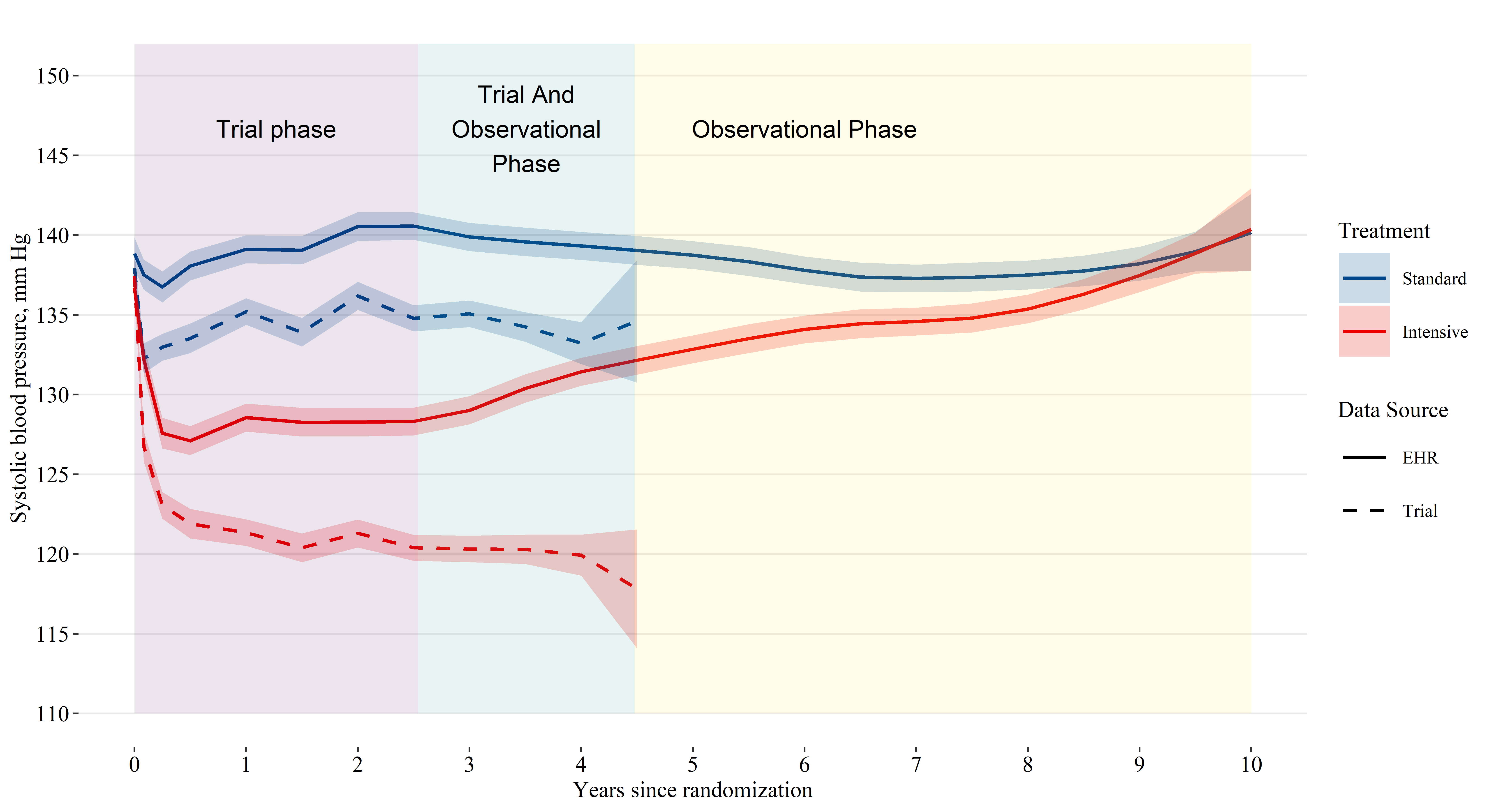
The trial phase and observational phase do not overlap for individual participants, but due to participants being randomized on different days, there is an overlap in the trial and observational phase for the population when time is measured relative to the date of randomization.

**Figure 4**: Cardiovascular mortality hazard ratio subgroup analysis for participants randomized to intensive versus standard treatment.



P-values test for heterogeneity in the treatment effect among subgroups and were not adjusted for multiple testing.

**Figure 5**: Mean systolic blood pressure over time by treatment group.



EHR denotes electronic health record. Shaded areas indicate a 95% confidence interval for the mean. The trial phase and observational phase do not overlap for individual participants, but due to participants being randomized on different days, there is an overlap in the trial and observational phase for the population when time is measured relative to the date of randomization.

**Online supplement only**

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**eTable 1**: Characteristics of study participants.

| **Characteristic** | **Overall N = 9,361** | **Treatment** | | **Included in EHR ancillary study** | | **p-valuea b** |
| --- | --- | --- | --- | --- | --- | --- |
| **Standard N = 4,683** | **Intensive N = 4,678** | **No N = 6,417** | **Yes N = 2,944** |
| Age, years | 67.9 (9.4) | 67.9 (9.5) | 67.9 (9.4) | 67.7 (9.6) | 68.5 (9.1) | <0.001 |
| Age ≥75 years | 28.2 | 28.2 | 28.2 | 27.4 | 29.9 | 0.012 |
| Female | 35.6 | 35.2 | 36.0 | 43.4 | 18.5 | <0.001 |
| Black | 31.5 | 31.9 | 31.1 | 32.0 | 30.3 | 0.086 |
| Systolic blood pressure | 139.7 (15.6) | 139.7 (15.4) | 139.7 (15.8) | 140.5 (15.8) | 137.8 (14.9) | <0.001 |
| Intensive treatment | 50.0 |  |  | 49.8 | 50.3 | 0.6 |
| Included in EHR ancillary study | 31.4 | 31.2 | 31.7 |  |  |  |
| Chronic Kidney Diseasec | 25.0 | 25.0 | 25.1 | 24.2 | 26.8 | 0.007 |
| MoCA ≤10th percentile | 27.0 | 26.9 | 27.1 | 27.2 | 26.5 | 0.5 |
| Frailty Status |  |  |  |  |  | <0.001 |
| Fit (FI≤0.10) | 15.9 | 15.7 | 16.2 | 16.9 | 13.7 |  |
| Pre-frail (0.10<FI≤0.21) | 51.2 | 51.7 | 50.8 | 51.9 | 49.8 |  |
| Frail (FI>0.21) | 32.9 | 32.7 | 33.1 | 31.2 | 36.5 |  |
| Table values are mean (standard deviation) or percentage. | | | | | | |
| a P-values computed using Wilcoxon rank sum test for continuous variables and chi-square test for categorical variables. | | | | | | |
| b Hypothesis tests compare the characteristics of participants included versus excluded from the ancillary study of blood pressure levels using data from the electronic health record. | | | | | | |
| c Chronic Kidney Disease was defined by an estimated glomerular filtration rate <60 ml/min/1.73 m2 based on the 2021 CKD-EPI creatinine equation. | | | | | | |
| Abbreviations: EHR = electronic health records; FI = frailty index; and MoCA = Montreal cognitive assessment | | | | | | |

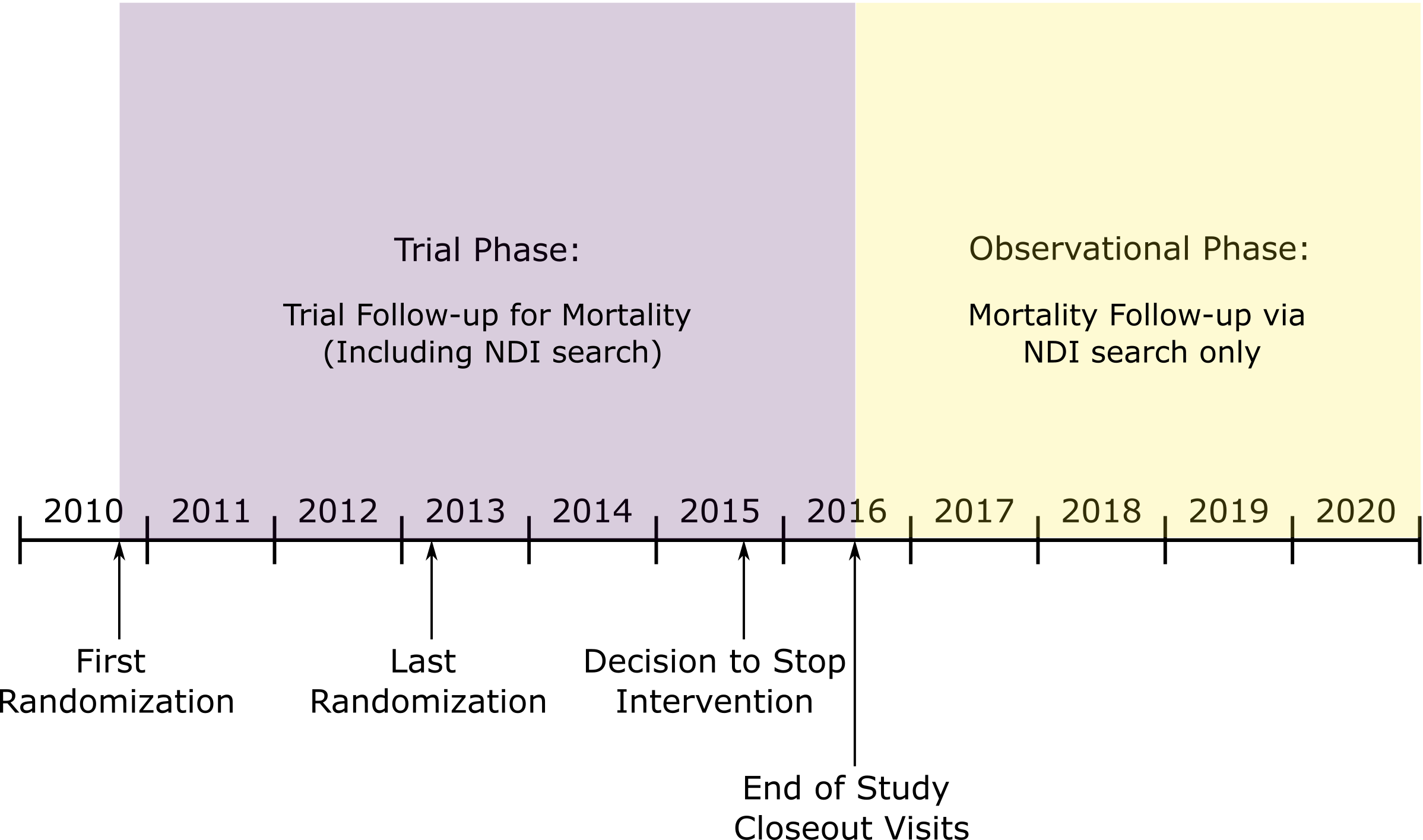
**eTable 2**: All-cause mortality by treatment group and subgroup

|  | **Trial Phase** | | | | | **Observational Phase** | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **N Events / N Total** | | **Incidence (95% CI)a** | | **Hazard Ratio (95% CI)** | **N Events / N Total** | | **Incidence (95% CI)** | | **Hazard Ratio (95% CI)** |
| **Standard** | **Intensive** | **Standard** | **Intensive** | **Standard** | **Intensive** | **Standard** | **Intensive** |
| Overall | 290 / 4,683 | 241 / 4,678 | 15.1 (13.4, 16.9) | 12.5 (11.0, 14.2) | 0.83 (0.68, 1.01) | 536 / 4,260 | 577 / 4,274 | 29.6 (27.1, 32.1) | 31.9 (29.3, 34.5) | 1.08 (0.94, 1.23) |
| *Age group* | | | | | | | | | | |
| <75 years | 137 / 3,364 | 115 / 3,361 | 9.7 (8.2, 11.5) | 8.2 (6.8, 9.8) | 0.84 (0.63, 1.11) | 257 / 3,129 | 246 / 3,123 | 18.9 (16.7, 21.3) | 18.1 (15.9, 20.5) | 0.96 (0.78, 1.17) |
| ≥75 years | 153 / 1,319 | 126 / 1,317 | 29.8 (25.3, 34.7) | 24.3 (20.3, 28.8) | 0.82 (0.62, 1.07) | 279 / 1,131 | 331 / 1,151 | 61.6 (54.7, 69.1) | 73.3 (65.7, 81.5) | 1.21 (1.00, 1.46) |
| *Sex* | | | | | | | | | | |
| Male | 212 / 3,035 | 170 / 2,994 | 17.2 (15.0, 19.6) | 13.8 (11.9, 16.0) | 0.80 (0.64, 1.01) | 353 / 2,743 | 400 / 2,745 | 30.3 (27.3, 33.6) | 34.6 (31.3, 38.1) | 1.14 (0.97, 1.34) |
| Female | 78 / 1,648 | 71 / 1,684 | 11.4 (9.0, 14.1) | 10.2 (8.0, 12.8) | 0.89 (0.61, 1.28) | 183 / 1,517 | 177 / 1,529 | 28.2 (24.3, 32.5) | 27.0 (23.2, 31.2) | 0.94 (0.74, 1.20) |
| *Race* | | | | | | | | | | |
| Non-Black | 209 / 3,190 | 173 / 3,224 | 16.0 (13.9, 18.2) | 13.0 (11.2, 15.0) | 0.80 (0.64, 1.01) | 386 / 2,897 | 426 / 2,953 | 31.4 (28.4, 34.6) | 34.2 (31.1, 37.6) | 1.10 (0.94, 1.28) |
| Black | 81 / 1,493 | 68 / 1,454 | 13.2 (10.5, 16.3) | 11.5 (8.9, 14.4) | 0.85 (0.59, 1.24) | 150 / 1,363 | 151 / 1,321 | 25.7 (21.8, 30.0) | 26.7 (22.6, 31.1) | 1.02 (0.78, 1.32) |
| *Chronic Kidney Diseaseb* | | | | | | | | | | |
| No | 163 / 3,491 | 126 / 3,485 | 11.3 (9.7, 13.1) | 8.7 (7.3, 10.4) | 0.77 (0.59, 1.01) | 316 / 3,232 | 349 / 3,250 | 22.7 (20.3, 25.2) | 25.0 (22.5, 27.7) | 1.08 (0.91, 1.29) |
| Yes | 125 / 1,161 | 112 / 1,170 | 26.5 (22.1, 31.4) | 23.6 (19.5, 28.2) | 0.89 (0.66, 1.19) | 220 / 1,007 | 227 / 1,012 | 53.8 (47.0, 61.2) | 55.5 (48.6, 63.1) | 1.02 (0.82, 1.26) |
| *Cognitive Function* | | | | | | | | | | |
| >10th percentile | 212 / 3,397 | 152 / 3,389 | 15.1 (13.1, 17.2) | 10.8 (9.1, 12.6) | 0.70 (0.55, 0.89) | 357 / 3,101 | 408 / 3,125 | 26.9 (24.2, 29.8) | 30.7 (27.8, 33.8) | 1.13 (0.96, 1.33) |
| ≤10th percentile | 77 / 1,253 | 83 / 1,257 | 15.3 (12.1, 19.0) | 16.5 (13.2, 20.3) | 1.13 (0.79, 1.62) | 176 / 1,135 | 165 / 1,131 | 36.8 (31.7, 42.6) | 34.7 (29.6, 40.2) | 0.98 (0.76, 1.26) |
| *Frailty Status* | | | | | | | | | | |
| Fit (FI ≤ 0.10) | 21 / 729 | 18 / 751 | 6.9 (4.4, 10.3) | 5.7 (3.4, 8.7) | 0.90 (0.43, 1.87) | 34 / 685 | 42 / 715 | 11.3 (7.9, 15.5) | 13.4 (9.7, 17.8) | 1.26 (0.72, 2.2) |
| Pre-frail (0.10 < FI ≤ 0.21) | 107 / 2,406 | 93 / 2,359 | 10.7 (8.8, 12.8) | 9.5 (7.7, 11.6) | 0.90 (0.66, 1.24) | 251 / 2,244 | 261 / 2,193 | 26.1 (23.0, 29.5) | 27.8 (24.5, 31.3) | 1.07 (0.87, 1.30) |
| Frail (FI > 0.21) | 161 / 1,523 | 127 / 1,538 | 26.4 (22.5, 30.7) | 20.4 (17.1, 24.2) | 0.75 (0.57, 0.98) | 251 / 1,317 | 274 / 1,349 | 46.2 (40.7, 52.2) | 49.9 (44.2, 56.0) | 1.07 (0.87, 1.30) |
| aIncidence is presented as the expected rate of events per 1,000 person-years. | | | | | | | | | | |
| bChronic Kidney Disease was defined by an estimated glomerular filtration rate <60 ml/min/1.73 m2 based on the 2021 CKD-EPI creatinine equation. | | | | | | | | | | |
| Abbreviations: CI = confidence interval; and FI = frailty index | | | | | | | | | | |

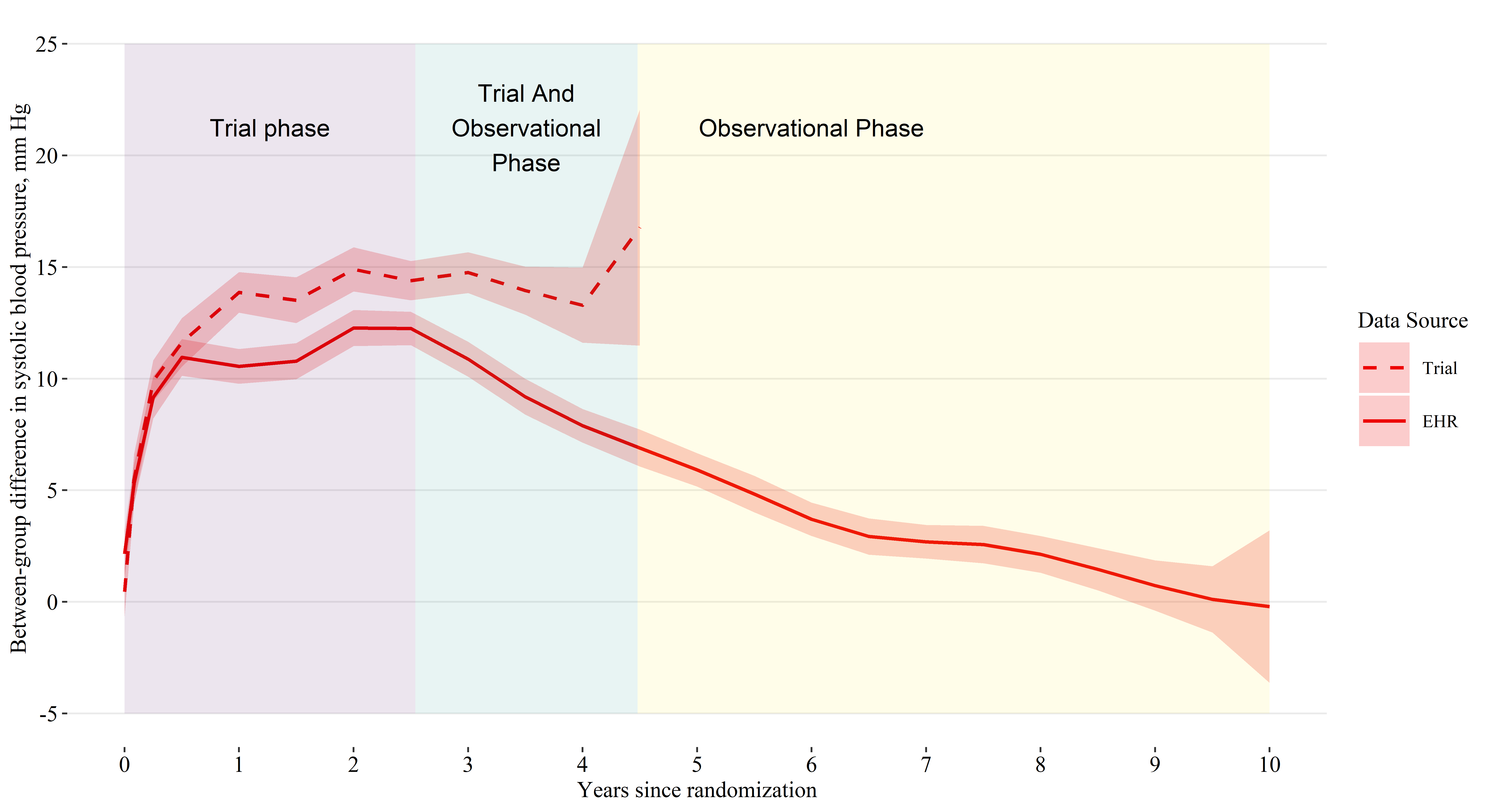
**eTable 3**: Cardiovascular and non-cardiovascular mortality by treatment group and subgroup

|  | **Trial Phase** | | | | **Observational Phase** | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **N CVD / non-CVD / Total** | | **Hazard Ratio (95% CI)** | | **N CVD / non-CVD / Total** | | **Hazard Ratio (95% CI)** | |
| **Standard** | **Intensive** | **CVD** | **Non-CVD** | **Standard** | **Intensive** | **CVD** | **Non-CVD** |
| Overall | 92 / 198 / 4,683 | 65 / 176 / 4,678 | 0.66 (0.49, 0.89) | 0.89 (0.71, 1.10) | 181 / 355 / 4,260 | 183 / 394 / 4,274 | 1.02 (0.84, 1.24) | 1.13 (0.97, 1.31) |
| *Age group* | | | | | | | | |
| <75 years | 45 / 92 / 3,364 | 27 / 88 / 3,361 | 0.53 (0.36, 0.79) | 0.95 (0.68, 1.32) | 81 / 176 / 3,129 | 73 / 173 / 3,123 | 0.92 (0.66, 1.28) | 1.01 (0.84, 1.22) |
| ≥75 years | 47 / 106 / 1,319 | 38 / 88 / 1,317 | 0.78 (0.49, 1.26) | 0.81 (0.61, 1.09) | 100 / 179 / 1,131 | 110 / 221 / 1,151 | 1.07 (0.81, 1.42) | 1.23 (0.99, 1.53) |
| *Sex* | | | | | | | | |
| Male | 68 / 144 / 3,035 | 47 / 123 / 2,994 | 0.62 (0.42, 0.90) | 0.85 (0.67, 1.08) | 119 / 234 / 2,743 | 125 / 275 / 2,745 | 1.09 (0.85, 1.38) | 1.20 (1.00, 1.44) |
| Female | 24 / 54 / 1,648 | 18 / 53 / 1,684 | 0.75 (0.45, 1.27) | 0.97 (0.64, 1.48) | 62 / 121 / 1,517 | 58 / 119 / 1,529 | 0.89 (0.63, 1.28) | 0.98 (0.71, 1.34) |
| *Race* | | | | | | | | |
| Non-Black | 67 / 142 / 3,190 | 44 / 129 / 3,224 | 0.58 (0.42, 0.81) | 0.87 (0.68, 1.12) | 126 / 260 / 2,897 | 135 / 291 / 2,953 | 1.10 (0.89, 1.37) | 1.13 (0.94, 1.36) |
| Black | 25 / 56 / 1,493 | 21 / 47 / 1,454 | 0.82 (0.46, 1.45) | 0.93 (0.64, 1.37) | 55 / 95 / 1,363 | 48 / 103 / 1,321 | 0.81 (0.54, 1.23) | 1.10 (0.84, 1.44) |
| *Chronic Kidney Diseasea* | | | | | | | | |
| No | 50 / 113 / 3,491 | 29 / 97 / 3,485 | 0.55 (0.36, 0.83) | 0.87 (0.65, 1.14) | 90 / 226 / 3,232 | 101 / 248 / 3,250 | 1.14 (0.84, 1.55) | 1.09 (0.90, 1.33) |
| Yes | 41 / 84 / 1,161 | 36 / 76 / 1,170 | 0.81 (0.51, 1.31) | 0.88 (0.62, 1.24) | 91 / 129 / 1,007 | 82 / 145 / 1,012 | 0.89 (0.67, 1.16) | 1.18 (0.93, 1.49) |
| *Cognitive Function* | | | | | | | | |
| >10th percentile | 62 / 150 / 3,397 | 40 / 112 / 3,389 | 0.56 (0.36, 0.88) | 0.74 (0.58, 0.96) | 128 / 229 / 3,101 | 122 / 286 / 3,125 | 0.93 (0.73, 1.19) | 1.25 (1.03, 1.53) |
| ≤10th percentile | 29 / 48 / 1,253 | 23 / 60 / 1,257 | 0.76 (0.41, 1.43) | 1.22 (0.83, 1.78) | 52 / 124 / 1,135 | 58 / 107 / 1,131 | 1.18 (0.81, 1.72) | 0.90 (0.72, 1.12) |
| *Frailty Status* | | | | | | | | |
| Fit (FI ≤ 0.10) | 7 / 14 / 729 | 1 / 17 / 751 | 0.14 (0.02, 1.12) | 1.22 (0.59, 2.5) | 8 / 26 / 685 | 7 / 35 / 715 | 0.77 (0.31, 1.95) | 1.26 (0.78, 2.0) |
| Pre-frail (0.10 < FI ≤ 0.21) | 34 / 73 / 2,406 | 23 / 70 / 2,359 | 0.59 (0.34, 1.03) | 1.00 (0.73, 1.37) | 75 / 176 / 2,244 | 81 / 180 / 2,193 | 1.07 (0.77, 1.50) | 1.04 (0.85, 1.27) |
| Frail (FI > 0.21) | 51 / 110 / 1,523 | 41 / 86 / 1,538 | 0.77 (0.53, 1.13) | 0.75 (0.56, 1.00) | 98 / 153 / 1,317 | 95 / 179 / 1,349 | 1.01 (0.77, 1.33) | 1.20 (0.96, 1.50) |
| aChronic Kidney Disease was defined by an estimated glomerular filtration rate <60 ml/min/1.73 m2 based on the 2021 CKD-EPI creatinine equation. | | | | | | | | |
| Abbreviations: CI = confidence interval; CVD = cardiovascular disease; and FI = frailty index | | | | | | | | |

**eFigure 1**: Timeline of landmark events and definition of ‘trial’ and ‘observational’ periods for the current analysis



**eFigure 2**: Mean difference in systolic blood pressure measured in the trial and as part of routine clinical practice over time.



Shaded areas indicate a 95% confidence interval for the mean.

EHR denotes electronic health record.