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ORIGINAL INVESTIGATION

Low blood pressure levels for fall injuries in older adults: the Health, Aging and Body Composition Study

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Abstract

Fall injuries cause morbidity and mortality in older adults. We assessed if low blood pressure (BP) is associated with fall injuries, including sensitivity analyses stratified by antihypertensive medications, in community-dwelling adults from the Health, Aging and Body Composition Study ($N = 1819$; age 76.6 ± 2.9 years; 53% women; 37% black). Incident fall injuries ($N = 570$ in 3.8 ± 2.4 years) were the first Medicare claims event from clinic visit (7/00–6/01) to 12/31/08 with an ICD-9 fall code and non-fracture injury code, or fracture code with/without a fall code. Participants without fall injuries ($N = 1249$) were censored over 6.9 ± 2.1 years. Cox regression models for fall injuries with clinically relevant systolic BP (SBP; ≤ 120, ≤ 130, ≤ 140, > 150 mmHg) and diastolic BP (DBP; ≤ 60, ≤ 70, ≤ 80, > 90 mmHg) were adjusted for demographics, body mass index, lifestyle factors, comorbidity, and number and type of medications. Participants with versus without fall injuries had lower DBP (70.5 ± 11.2 vs. 71.8 ± 10.7 mmHg) and used more medications (3.8 ± 2.9 vs. 3.3 ± 2.7); all $P < 0.01$. In adjusted Cox regression, fall injury risk was increased for DBP ≤ 60 mmHg (HR = 1.25; 95% CI 1.02–1.53) and borderline for DBP ≤ 70 mmHg (HR = 1.16; 95% CI 0.98–1.37), but was attenuated by adjustment for number of medications (HR = 1.22; 95% CI 0.99–1.49 and HR = 1.12; 95% CI 0.95–1.32, respectively). Stratifying by antihypertensive medication, DBP ≤ 60 mmHg increased fall injury risk only among those without use (HR = 1.39; 95% CI 1.02–1.90). SBP was not associated with fall injury risk. Number of medications or underlying poor health may account for associations of low DBP and fall injuries.

Keywords Fall injury · Low blood pressure · Diastolic blood pressure · Polypharmacy

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Introduction

Fall injuries are an important cause of morbidity and mortality in older adults. Studies report that approximately 30% of community-dwelling adults over 65 years old fall each year (O'Loughlin et al. 1993; Tromp et al. 2001), with the proportion increasing to 50% by age 80 years (Tinetti and Williams 1997). Of these falls, the majority cause physical injuries, including 5–20% with serious events (e.g., fractures, joint distortions and dislocations, brain injuries, soft tissue injuries) (Stel et al. 2004; Kannus et al. 2005). Furthermore, over 80% of injury-related admissions to hospitals among people over 65 years old are attributed to falls (Kannus et al. 2005). In the USA (US) in 2015, over 3 million older adults were treated in emergency departments for fall injuries (Center for Disease Control and Prevention 2017), with the overall number and the age-adjusted rates of fall-related injuries rising from 2001 to 2012 (Orces and Alamgir 2014) and expected to further increase with the growing number of older adults. The fall injuries are costly, both in terms of medical expenditures and subsequent health outcomes. A systematic review of studies in the USA, Europe and Australia reported the mean cost per fall injury to be approximately $10,000 US dollars, with hospitalization costs estimated at over $26,000 US dollars per fall (Davis et al. 2010). Fall-induced injuries may cause loss of independence, disability, admission to a nursing home, and increased risk of death (Tinetti and Williams 1997; Kannus et al. 2005).

Identifying risk factors for all fall injuries, including outpatient events and non-fracture injuries, is an important public health priority. Known risk factors of falls include impaired balance and gait, polypharmacy, visual impairment, and cognitive decline (Ambrose et al. 2013). Risk factors for fractures include propensity to fall, older age and lower body mass index (Ensrud 2013). Some studies suggest cardiovascular diseases and orthostatic hypotension are fall risk factors (Shaw and Claydon 2014), with transient cerebral ischemia as a potential mechanism. However, assessment of orthostatic hypotension is time-consuming and difficult in standard medical practice. Furthermore, current recommendations for assessing orthostatic hypotension may be inadequate to diagnose all of those with orthostatic hypotension (Campos et al. 2015). Although conventional blood pressure (BP) measurements are easily conducted in clinical practice, only a few investigations in community-dwelling older adults have examined the association between BP and falls or fractures, with BP levels for fall risk varying among studies (Kario et al. 2001; Gangavati et al. 2011; Klein et al. 2013) and inconsistent results on the role of antihypertensive medications (Leipzig et al. 1999; Wiens et al. 2006; Woolcott et al. 2009; Tinetti et al. 2014). Additionally, clinically relevant BP levels for risk of total fall injuries have not been comprehensively explored. The objective of our study was to investigate both systolic and diastolic BP levels as a risk factor for fall injuries and the role of antihypertensive medications in this relationship.

Methods

Study design and participants

The Health, Aging and Body Composition (Health ABC) Study is a prospective cohort study designed to investigate if changes in body composition act as a common pathway by which multiple diseases affect morbidity, disability and risk of mortality in community-dwelling older adults, and included 3075 participants (48.4% male, 41.6% black) aged 70–79 at baseline (1997/1998) (De Rekeneire et al. 2003). Participants were recruited by mail from specified zip codes surrounding Memphis, Tennessee, and Pittsburgh, Pennsylvania, followed by a telephone eligibility screen. All participants were eligible Medicare beneficiaries, the US federal health insurance program for those ≥ 65 years. Whites were recruited from a random sample of Medicare beneficiaries. Blacks were recruited from Medicare beneficiaries and all age-eligible residents in these areas. Eligibility criteria included self-report of no difficulty walking one-quarter of a mile or climbing 10 steps without resting, no difficulty performing mobility-related activities of daily living (ADLs), no life-threatening cancers with active treatment within the past 3 years, and no plans to move out of the area in the next 3 years. The institutional review boards at the participating institutions approved the study protocol, and written informed consent was obtained before testing. Our study included participants from a subsample of 1819 participants with BP at the 2000/01 clinic visit and linked Medicare data from an ancillary project. Reasons for exclusion were missing BP measures due to a home visit ($N = 74$), telephone visit ($N = 233$), proxy visit ($N = 63$), other reason for missed visit ($N = 105$), withdrawal from the study ($N = 9$), death ($N = 187$), or missing BP measures at the examination ($N = 41$); and lack of Medicare Fee-for-Service Parts A and B (but not C) Medicare claims ($N = 544$) (Fig. 1).

Outcome measure

The first fall injury after the clinic visit (7/00–6/01) to 12/31/08 was defined from linked Medicare claims available from denominator (demographic and enrollment information), inpatient, outpatient, physician/supplier, and carrier (claims from non-institutional providers, such as nurse practitioners and independent clinical laboratories) files.

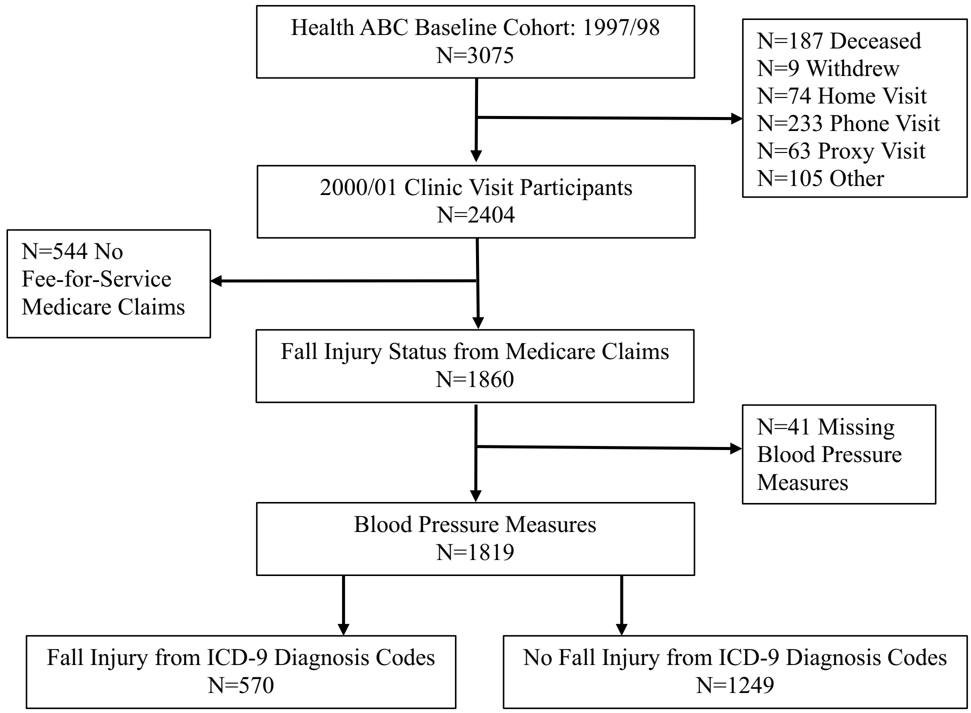

Fig. 1 Participant flowchart

The Medicare claims used were Fee-for-Service Parts A (inpatient) and B (outpatient), but not C (Medicare Advantage Plans which are offered by private companies). Falls were ascertained using ICD-9 E-codes which describe the "mechanism of injury" and injuries and fractures were ascertained with ICD-9 billing codes from Medicare claims. First unique event with an ICD-9 fall code (E880-888) and non-fracture injury ($N = 146$), or a fracture code (800-829) with/without a fall code ($N = 424$) was considered the incident event. All traumatic injuries (e.g., motor vehicle accidents), intentional injuries, and pathologic injuries were excluded from events ($N = 38$). Those without fall injuries were censored at the end of Medicare Fee-for-Service coverage ($N = 1$) or last follow-up ($N = 11$)/death ($N = 382$)/Medicare dataset end date ($N = 855$). In the adjudication of our diagnoses code algorithm, a subset of Medicare fall injuries was compared to the self-reported fall injuries with medical records. The injuries to adjudicate ($N = 192$) were included due to potential uncertainty of particular diagnoses codes to classify a primary fall injury: concurrent stroke code ($N = 13$); fall code with uncertain injury ($N = 50$); fracture code that was not in 1st or 2nd position (i.e., not listed as the 1st or 2nd reason for visit billing, $N = 34$); vertebral column/rib fracture without a fall code ($N = 95$). Overall, the fall injury adjudication showed an excellent agreement with our Medicare algorithms, although only 50% of vertebral fractures in Medicare claims were related to falls in medical records and therefore we required a fall code for any vertebral fractures that were included as events.

Primary independent variables–blood pressure

BP was measured by centrally trained and certified staff after 5 min of quiet rest while sitting. The average of two seated measurements was used. BP levels for sitting systolic BP (SBP) of ≤ 120, ≤ 130, ≤ 140, and > 150 mmHg, and sitting diastolic BP (DBP) of ≤ 60, ≤ 70, ≤ 80, and > 90 mmHg were evaluated. These BP level categories, which were not mutually exclusive, were based on clinically relevant past work on BP levels including relationships with falls (Kario et al. 20011; Klein et al. 2013), guidelines on BP management (Aronow et al. 2011), and the *J*-shape curve correlating BP and total mortality (Protogerou et al. 2007; Moreira et al. 2014).

Covariates–medication

Participants brought all medications that were taken within the prior month of the 1999/2000 to the clinic visit. The Iowa Drug Information System codes were used for categorization of these medication data (Pahor et al. 1994). Specifically, we classified use of medications known to increase falls and antihypertensive medications as per a previously published approach (Marcum et al. 2015). The total number of medications was also counted.

Additional covariates

Covariates were measured concurrent with the 2000/01 visit unless noted otherwise. Age, sex, race, and study site were determined at study enrollment. Height and weight were measured by study staff using a stadiometer and a calibrated balance beam scale. Body mass index (BMI) was defined as weight (in kilograms) divided by height (in meters) squared. Resting heart rate was automatically assessed from a 12-lead electrocardiogram. Smoking status (current, past, never; 1999/2000), alcohol consumption (> 1 drink/week; baseline), education (≥ high school; baseline), poor vision (poor eyesight, cataract, glaucoma, retinal disease, and/or macular degeneration; baseline), baseline cardiovascular disease (bypass or coronary artery bypass graft, carotid endarterectomy, myocardial infarction, angina pectoris, or congestive heart failure) and cerebrovascular disease (stroke or transient ischemic attack), history of falls in past 12 months, frequency of falls in past 12 months (0, 1, ≥ 2), knee pain for > 1 months in past 12 months or most days in 30 days, leg pain when walking, and self-reported physical activity calculated as kcal/kg per week spent walking and climbing stairs (Ainsworth et al. 1993) were measured by questionnaire. Diabetes mellitus was defined as self-reported physician diagnosis, hypoglycemic medication use, or fasting glucose ≥ 126 mg/dL (47.0 mmol/L) after an 8-h fast (American Diabetes Association 2015). Depressive symptoms were assessed with Center for Epidemiologic Studies Depression Scale (CES-D) (Roberts and Vernon 1983). Modified Mini-Mental State Examination (3MSE) score (1999/2000) measured cognitive function and Digit Symbol Substitution Test (DSST) measured attention, psychomotor speed, and executive function (Mehta et al. 2004). ADL limitations were assessed as severe difficulty or inability to do any four ADL components available at the 2000/01 visit (walk, get in and out of bed, bathe or shower, and dress). Usual gait speed over 6 m was administered in the examination. Ability to rise from chair was attempted once with arms folded. Knee extensor strength was measured concentrically at 60° per second using an isokinetic dynamometer (125 AP dynamometer; Kin-Com, Harrison, Tennessee). Participants performed three to six trials, and the maximal torque of the three best trials was averaged (Newman et al. 2003). Sensory nerve impairment was defined as insensitivity to 10-gram monofilament (Ward et al. 2013). BP in the right arm and both ankles was measured with standard cuffs and a pencil Doppler flow probe (Parks Medical Electronics, Inc., Aloha, Oregon) to obtain Ankle–brachial index (ABI), which assessed peripheral arterial disease (ABI ≤ 0.9) and arterial stiffening (ABI > 1.3) on the worst side (Sillesen and Falk 2011). Poor renal function was defined as cystatin C level > 1 mg/dL (Shlipak et al. 2006).

Statistical analyses

Means and frequencies of characteristics for those with versus without fall injury were compared using *t* test, Wilcoxon rank-sum test, and Chi-squared statistics as appropriate. Time to first fall injury outcome was modeled using multivariate Cox proportional hazards (Cox PH) regression. Main BP level predictors were examined in separate models. Four sets of models were built: (1) BP levels adjusting for age, sex, race, study site, and BMI, (2) Model 1 plus use of medications known to increase the risk of falls and antihypertensive medications, (3) Model 2 plus total number of additional medications (not already accounted for by medications in Model 2), (4) Model 3 plus additional covariates related to the outcome or the predictor using an alpha level of 0.10. To minimize collinearity, additional covariates were subsequently removed at a *P* value of > 0.10 and if the effect of BP was not modified > 10%. Separate models for nonfracture and fracture injuries were also built. Main analyses were additionally adjusted for multiple comparisons using Bonferroni methods. Sensitivity analyses were done stratified by antihypertensive medication use, stratified by fall history (any vs. none), including medications for Model 2 in the total number of medications, removing events with ICD-9 vertebral fracture codes (805-806) without a concurrent fall code (*N* = 53), and removing participants who died within 2 years. SAS version 9.4 (SAS Institute, Inc., Cary, NC) was used for statistical analyses.

Results

At the 2000/01 clinic visit, participants were aged 76.6 ± 2.9 years. Fifty-three percent were women and 37% were black. Mean systolic and diastolic BPs were 134.7 ± 19.7 and 71.4 ± 10.9 mmHg, respectively. Incident fall injuries occurred in 570 participants (31%) over 3.8 ± 2.4 years, and those without fall injuries (*N* = 1249) were followed until the last available data over 6.9 ± 2.1 years. The rate of total fall injury was 53 per 1000 person-years. Most incident injuries were fractures (*N* = 424/570; 74%). Participants with fall injuries were older, had lower BMI, were less likely to be a current or past smoker, and were more likely to be women, white, and had higher education (Table 1). Participants with fall injuries were more likely to have poor vision, cerebrovascular disease, a fall history and a higher frequency of falls, inability to rise from chair, ≥ 1 ADL limitation, antidepressant and antiepileptic medication use, a higher mean number of other medications, higher CES-D and DSST scores, and poorer knee extensor strength. No differences were found between those with and without total fall injuries for physical activity, diabetes, cardiovascular disease, use of other medications, 3MSE scores, knee or leg pain, gait speed < 0.8 m/sec, monofilament insensitivity, ABI, or cystatin C level > 1 mg/dL (Table 1).

Table 1 Participant characteristics by incident fall injury status

Characteristic	With fall injury $N = 570$	Without fall injury $N = 1249$
Age, years	77.0 ± 3.0[c]	76.5 ± 2.8
Women, *n* (%)	371 (65.1)[c]	590 (47.2)
Black race, *n* (%)	161 (28.3)[c]	511 (40.9)
Pittsburgh site, *n* (%)	250 (43.9)[a]	483 (38.7)
Body mass index, kg/m^2	26.7 ± 4.9[b]	27.5 ± 4.7
Heart rate, min	63.7 ± 10.3	63.2 ± 10.4
Current smoker, *n* (%)	28 (5.1)[b]	96 (7.9)
Past smoker, *n* (%)	232 (42.1)[b]	583 (47.7)
Alcohol > 1 drink/week, *n* (%)	269 (47.8)	632 (51.5)
≥ High school graduate, *n* (%)	454 (80.4)[b]	912 (74.1)
Physical activity, kcal/kg/week	5.36 ± 18.8	6.11 ± 17.63
Poor vision, *n* (%)	323 (56.7)[a]	630 (50.4)
Diabetes mellitus	117 (20.5)	273 (21.9)
Cardiovascular disease	96 (17.1)	208 (17.0)
Cerebrovascular disease	50 (8.9)[a]	80 (6.5)
Fall history, *n* (%)	183 (32.2)[c]	271 (21.8)
Antidepressants, *n* (%)	28 (4.9)[a]	34 (2.7)
Antiepileptics, *n* (%)	28 (4.9)[c]	22 (1.8)
Antihypertensives, *n* (%)	323 (56.7)	733 (58.7)
Antipsychotics, *n* (%)	1 (0.2)	9 (0.7)
Benzodiazepines, *n* (%)	28 (4.9)	62 (5.0)
Opioids, *n* (%)	19 (3.3)	29 (2.3)
Total number of medications	3.78 ± 2.87[c]	3.30 ± 2.66
CES-D	6.98 ± 6.70[a]	6.34 ± 6.45
3MSE score	90.5 ± 7.9	89.9 ± 8.5
Digit symbol score	38.6 ± 13.8[c]	35.6 ± 14.6
Knee or leg pain, *n* (%)	231 (40.7)	479 (38.5)
Gait speed < 0.8 m/sec, *n* (%)	61 (10.8)	108 (8.8)
Inability to rise from chair, *n* (%)	57 (10.1)[a]	87 (7.1)
≥ 1 ADL limitation, *n* (%)	117 (20.6)[b]	192 (15.4)
Average max torque, Nm	86.3 ± 31.3[c]	96.8 ± 35.0
10-g monofilament insensitivity, *n* (%)	55 (9.9)	119 (9.7)
Ankle–brachial index		
ABI ≤ 0.9, *n* (%)	88 (15.1)	269 (16.3)
ABI > 1.3, *n* (%)	31 (5.3)	84 (5.1)
Cystatin C > 1.0, *n* (%)	171 (31.1)	325 (26.6)

Data are mean ± SD unless otherwise specified

CES-D Center for Epidemiologic Studies Depression Scale score, *3MSE* Modified Mini-Mental State Examination, *ABI* Ankle–brachial index

$P <$ [a]0.05, $P <$ [b]0.01, $P <$ [c]0.001

Lower DBP and DBP ≤ 60 mmHg and ≤ 70 mmHg were more likely to be observed in participants with fall injuries compared to those without fall injuries (Table 2, BP categories not mutually exclusive). Neither DBP levels of ≤ 80 nor > 90 mmHg were associated with fall injury. DBP subgroups with ≤ 70 mmHg had the highest proportion of incident fall injury: 38% of participants with DBP ≤ 60 mmHg and 32% of those with 60 < DBP ≤ 70 mmHg (Fig. 2). Fitting linear and quadratic DBP terms in a Cox PH model yielded a positive quadratic term ($P = 0.03$ for both) (Table 2).

Figure 3 shows adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) for different DBP levels predicting fall injuries. DBP ≤ 60 mmHg was significantly associated (HR = 1.25; 95% CI 1.02–1.53) and DBP ≤ 70 mmHg (HR = 1.16; 95% CI 0.98–1.37) was borderline associated with increased fall injury risk after adjusting for age,

Table 2 Blood pressure, pulse pressure, and orthostatic hypotension by total sample and incident fall injury status

	Total sample $N = 1819$	With fall injury $N = 570$	Without fall injury $N = 1249$
Systolic blood pressure (SBP), mmHg	134.7 ± 19.7	135.1 ± 20.6	134.5 ± 19.2
SBP ≤ 120 mmHg, *n* (%)[a]	457 (25.1)	140 (24.6)	317 (25.4)
SBP ≤ 130 mmHg, *n* (%)[a]	849 (46.7)	261 (45.8)	588 (47.1)
SBP ≤ 140 mmHg, *n* (%)[a]	1221 (67.1)	376 (66.0)	845 (67.7)
SBP > 150 mmHg, *n* (%)	314 (17.3)	102 (17.9)	212 (17.0)
Diastolic blood pressure (DBP), mmHg	71.4 ± 10.9	70.5 ± 11.2[b]	71.8 ± 10.7
DBP ≤ 60 mmHg, *n* (%)[a]	329 (18.1)	125 (21.9)[c]	204 (16.3)
DBP ≤ 70 mmHg, *n* (%)[a]	957 (52.6)	325 (57.0)[b]	632 (50.6)
DBP ≤ 80 mmHg, *n* (%)[a]	1522 (83.7)	479 (84.0)	1043 (83.5)
DBP > 90 mmHg, *n* (%)	60 (3.3)	18 (3.2)	42 (3.4)

[a]Blood pressure levels are not mutually exclusive

$P <$ [b]0.01, $P <$ [c]0.001 (with vs. without fall injury)

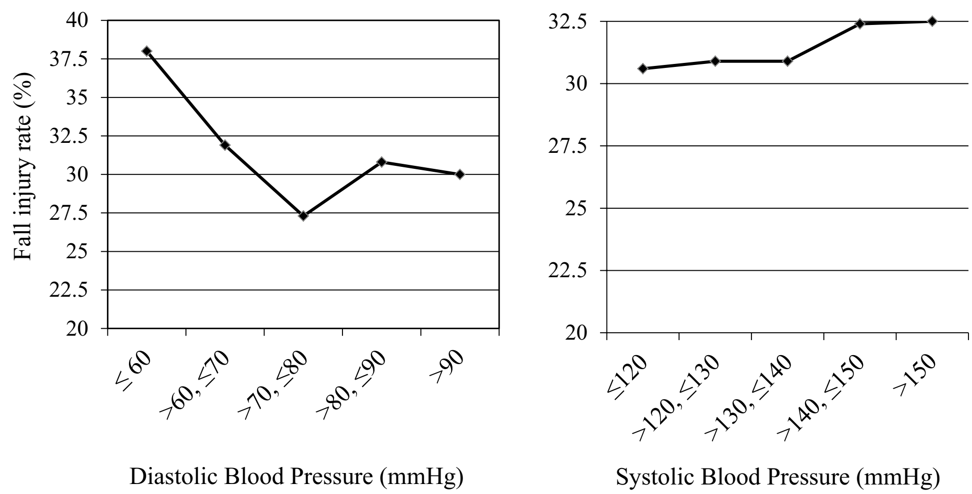

Fig. 2 Proportion with incident fall injury during follow-up by blood pressure group

sex, race, site, BMI, and medications known to increase the risk of falls (i.e., antidepressants, opioids, benzodiazepines, antipsychotics, antiepileptics, and antihypertensives; Model 2). DBP ≤ 60 mmHg became borderline associated with increased fall injury risk after adjustments for the total number of additional medications (Model 3 for both DBP ≤ 60 mmHg: HR = 1.22; 95% CI 0.99–1.49) and for the final model (HR = 1.21; 95% CI 0.99–1.49). The HR for total number of additional medications was 1.05 (95% CI 1.01–1.10) with HRs of variables in the final model shown in Table 3. Main results were consistent with multiple comparisons corrections.

The contribution of antihypertensive medications added individually to the final model for either DBP ≤ 60 or ≤ 70 mmHg did not change the HRs by more than 10% and were not significantly associated with fall injury risk. In sensitivity analyses stratified by antihypertensive medication use, DBP ≤ 60 mmHg among those without antihypertensive medication use was significantly associated with increased fall injury risk (HR = 1.44; 95% CI 1.05–1.96). Risk was not increased among those using antihypertensive medication (HR = 1.09; 95% CI 0.83–1.43) (*P* for interaction = 0.13).

None of the models for DBP ≤ 80 and > 90 mmHg, SBP ≤ 120, ≤ 130, ≤ 140, and > 150 mmHg were significant (not shown). Results were consistent when stratified for fracture and non-fracture fall injuries (not shown). Sensitivity analyses stratified by fall history, including medications in Model 2 in the total number of medications, removing vertebral fractures without a concurrent fall code, and removing participants who died within 2 years did not modify the results.

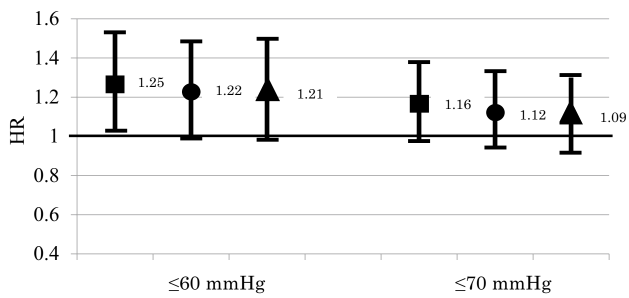

Fig. 3 Diastolic blood pressure levels and incident fall injury risk. Variables in Model 1 were kept in all models. Additional covariates were removed at $P > 0.10$. Models for each blood pressure level included same covariates. Model 1: adjusted for age, sex, race, site, and body mass index. Model 2 (black square): Model 1 + medication use (antidepressants, opioids, benzodiazepines, antipsychotics, antiepileptic medications, and antihypertensive medications). Model 3 (black circle): Model 1 + antidepressants, opioids, antiepileptic, total number of additional medications. Final Model 4 (black triangle): Model 1 + antiepileptic medications, total number of additional medications, fall history, Modified Mini-Mental State Examination score, and cystatin $C > 1.0$ mg/L

Table 3 Hazard ratios of predictors in final model

Variable	HR	95% CI
Diastolic blood pressure ≤ 60 mmHg	1.21	0.99–1.49
Age, years	1.06	1.03–1.09
Black	0.59	0.47–0.73
Women	1.76	1.47–2.12
Pittsburgh	1.25	1.05–1.49
Body mass index, kg/m^2	0.98	0.96–1.00
Antiepileptic medication	1.69	1.14–2.49
Total number of additional medications	1.05	1.01–1.10
Fall history	1.44	1.19–1.73
3MSE score	0.98	0.98–1.00
Cystatin C > 1.0 mg/L	1.22	1.01–1.48

3MSE Modified Mini-Mental State Examination

Discussion

In this prospective study of community-dwelling older white and black adults, evidence suggested that DBP ≤ 60 mmHg may be associated with elevated risk of fall injury. However, these results were attenuated after adjusting for total medication use and additional comorbidities. In addition, DBP ≤ 60 mmHg increased fall injury specifically among those not using antihypertensive medication. DBP levels associated with fall injury in our study were lower than DBP levels in previous studies of falls.

Our study is novel in that we examined all treated fall injuries, including incident non-fracture and fracture injuries, rather than falls alone, as fall injuries are more serious consequences resulting in opportunities for intervention during the health care provider visits. However, previous studies among community-dwelling older adults have found that low BP increased risk of falls. In community-dwelling older adults ≥ 65 years old, those with standing SBP < 140 mmHg had 2.8 times higher incidence of falls during 1 year of follow-up versus those with standing SBP ≥ 140 mmHg (Kario et al. 2001). In another study of community-dwelling older adults ≥ 60 years old, men with SBP < 120 mmHg and DBP < 80 mmHg had 2.5 times and 1.8 times higher risk of falls, respectively, versus men with 120 ≤ SBP < 140 and 80 ≤ DBP < 90 mmHg (Klein et al. 2013). These studies adjusted for the number of medical conditions, but did not control for severity of the conditions, or if these specific conditions required treatment or medication. Our work adjusted for important confounding factors in falls such as vision, cognition, peripheral neuropathy, and pain, in addition to a number of other comorbidities (e.g., cardiovascular disease, diabetes, etc.) entered individually into the models. We also included many medications known to be associated with falls and the total number of medications, a known risk factor for both falls and fractures (Lai et al. 2010; Ambrose et al. 2013) which was not considered in previous studies. After the adjustment for these important confounding factors, we found only DBP was associated with fall injuries.

Our findings indicated the importance of evaluating underlying medical conditions in studies of BP and fall injuries in older adults. Total medication use is a proxy for an individual's underlying health and comorbidity (Fried et al. 2014). Low BP may also indicate poor health such as weight loss, pump failure secondary to hypertension or ischemic heart disease, or previous myocardial infarction (Harris et al. 1997; Harris 2003). In a study of adults > 85 years old, low BP was more prevalent among those with poor health, with the inverse association of BP and mortality attenuated after adjustment for poor health (Boshuizen et al. 1998). Several studies have examined the importance of DBP specifically. In one study, lowest DBP category (≤ 70 mmHg) had the highest mortality rate among other DBP categories (70–79, 80–89, 90–99, 100–109, ≥ 110 mmHg) (Mattila et al. 1988). The results are similar to another finding that showed that DBP ≤ 60 mmHg predicts mortality in older adults (HR = 1.8 vs. DBP > 60 mmHg, Protogerou et al. 2007). In older adults with diabetes, lower DBP was found to be associated with a higher risk of mortality than lower SBP (decrease in 10 mmHg was associated with 26 and 20% increased mortality, respectively) (van Hateren et al. 2010). Our findings that DBP, but not SBP, was associated with fall injury suggest that DBP may be as important as SBP to take into account when considering benefits and risks of BP lowering, especially in older adults.

The characteristics of study participants need to be considered when comparing our results with other studies. Health ABC is a large longitudinal cohort with diversity by sex and race. Participants had no mobility limitations at baseline, and participants in our analyses had to have an initial clinic visit, with those missing clinic visits generally having poor health (e.g., older age, ADL difficulty, cognitive impairment) that limited participation at in-person visits as previously reported (Strotmeyer et al. 2010, Ward et al. 2014). Our rate of fall injury among those aged 73–82 years (mean 76.6 ± 2.9 years) at the start of our follow-up was 53 per 1000 person-years, significantly less than reported for those aged ≥ 75 years in National Health Interview Survey (women: 128 per 1000 person-years; men: 85.5 per 1000 person-years) (Verma et al. 2016). Use of ≥ 5 medications (30%) was also lower in our population than reported in a national survey of Medicare beneficiaries (46%) (Fried et al. 2014). We had fewer individuals with gait speed < 0.8 m/sec at the 2000/01 clinic visit compared to a national sample (44%) (Odden et al. 2012). However, over the 6.1 ± 2.6 years of follow-up, participants aged into their 80s and 30% developed mobility limitation over 8.5 years (Ward et al. 2014). Observational studies in community-dwelling older adults enable assessment of fall injury risk for those typically under-represented in clinical trials. For example, the Systolic Blood Pressure Intervention Trial which showed no difference in the risk of fall injury with SBP goals of < 120 mmHg or < 140 mmHg excluded those with SBP < 110 mmHg after 1 min of standing (9.4% of those screened for eligibility), diabetes, history of stroke, or prevalent dementia (Supiano and Williamson 2017). Our findings suggest that older community-dwelling adults with higher comorbidity burden than those included in clinical trials of BP lowering may have different relationships to fall injury risk, as we found that comorbidities may account for the associations of low DBP with fall injuries.

Our methods also make this study unique. Although the generalizability to those in different insurance coverage beyond Medicare coverage is uncertain, the link with Medicare claims allowed outcomes to be collected even if participants could not attend clinic visits and increased completeness of outcomes, particularly for our population recruited from Medicare beneficiaries. Our research is novel in that we included both inpatient and outpatient events. Although about three-quarters of our treated fall injuries were fractures, we examined incident non-fracture injuries, which may be earlier injuries than fractures for serious fall events. Compared to the review article by Kannus et al. (2005) which stated that about 5% of falls result in a fracture and 5–10% in other serious injury, we had more fractures. The studies in this article had varied definitions for fall injuries and differences in populations which may explain the prevalence of non-fracture injuries. In most of these studies, fall injury data were collected by self-report and over 60% of participants were women. In addition, these studies examined all fall injuries during the study period, whereas our study examined incident fall injuries. The wide range of measures allowed adjustment for numerous confounding factors, including medication use and a wide range of comorbidities. BP and important confounding factors such as medication use (1 year prior to the assessment of BP) were assessed at one point in time for our analyses, though past work indicates only small change in SBP and DBP occur over 5 years (Odden et al. 2016). Prevalence of hypertension was 80% at baseline and 70% of those with hypertension were using antihypertensive medications initially, so few likely initiated these (Sirois et al. 2009). Although the completeness of diagnostic codes for inpatient versus outpatient fall injury is uncertain, our agreement was excellent when claims were adjudicated to medical records for a subset of events including non-fracture injuries. E-codes and outpatient codes for fall injuries have been used in several studies and validated for fracture previously (Ray et al. 1992; Kim et al. 2016). Use of E-codes is mandatory in hospitals and emergency departments in Tennessee, but only mandatory in hospitals in Pennsylvania. Although use of E-codes may be more specific than sensitive for falls, these are the only indicators of falls in US diagnoses codes. We did not include enrollees in Medicare Part C, who were shown in the 1990s to be healthier with less health care costs compared to those in traditional Medicare Parts A and B (Newhouse et al. 2012). However, the differences in characteristics by type of Medicare enrollment have decreased with policy changes over time (Newhouse et al. 2012) and our analyses used Medicare enrollment from 2000 to 2001. Our novel approach combining outcomes of fall injuries from claims and the well-established cohort with multiple risk factors for fall injuries were methodologic strengths.

In our study, DBP ≤ 60 mmHg increased risk of fall injury, though were attenuated by total medication use and comorbidity. Our findings indicate that community-dwelling older adults with low DPB, particularly those not using antihypertensive medications, may be at increased risk of fall injuries. When assessing low DBP as a risk factor for fall injury in older adults, underlying poor health status should be considered as well.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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