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Standing beat-to-beat blood pressure variability is reduced among fallers in the Malaysian Elders Longitudinal Study

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Abstract

The aim of this study was to determine the relationship between falls and beat-to-beat blood pressure (BP) variability.

Continuous noninvasive BP measurement is as accurate as invasive techniques. We evaluated beat-to-beat supine and standing BP variability (BPV) using time and frequency domain analysis from noninvasive continuous BP recordings.

A total of 1218 older adults were selected. Continuous BP recordings obtained were analyzed to determine standard deviation (SD) and root mean square of real variability (RMSRV) for time domain BPV and fast-Fourier transform low frequency (LF), high frequency (HF), total power spectral density (PSD), and LF:HF ratio for frequency domain BPV.

Comparisons were performed between 256 (21%) individuals with at least 1 fall in the past 12 months and nonfallers. Fallers were significantly older ($P = .007$), more likely to be female ($P = .006$), and required a longer time to complete the Timed-Up and Go test (TUG) and frailty walk test ($P \leq .001$). Standing systolic BPV (SBPV) was significantly lower in fallers compared to nonfallers (SBPV-SD, $P = .016$; SBPV-RMSRV, $P = .033$; SBPV-LF, $P = .003$; SBPV-total PSD, $P = .012$). Nonfallers had significantly higher supine to standing ratio (SSR) for SBPV-SD, SBPV-RMSRV, and SBPV-total PSD ($P = .017$, $P = .013$, and $P = .009$). In multivariate analyses, standing BPV remained significantly lower in fallers compared to nonfallers after adjustment for age, sex, diabetes, frailty walk, and supine systolic BP. The reduction in frequency-domain SSR among fallers was attenuated by supine systolic BP, TUG, and frailty walk.

In conclusion, reduced beat-to-beat BPV while standing is independently associated with increased risk of falls. Changes between supine and standing BPV are confounded by supine BP and walking speed.

Abbreviations: BP = blood pressure, BPV = blood pressure variability, DBP = diastolic blood pressure, DBPV = diastolic blood pressure variability, FFT = fast fourier transform, HF = high frequency, LF = low frequency, PSD = power spectral density, RMSRV = root mean square of real variability, SBP = systolic blood pressure, SBPV = systolic blood pressure variability, SD = standard deviation, SSR = standing to supine ratio, TUG = Timed-Up and Go.

Keywords: Accidental falls, aged, blood pressure, blood pressure variability, noninvasive monitoring

1. Introduction

Injuries and other sequelae from falls rank highly among conditions affecting older persons, and are associated with increased mortality and morbidity as well as poorer overall functioning and early admission to long-term care facilities.[1–4] One of 3 older persons falls at least once during any 12-month period.[5–7] Falls are associated with increased hospitalization costs towing to injuries such as fractures, especially hip fractures.[3,4,6]

An overlap exists between falls and syncope in older persons.[7] Although orthostatic hypotension (OH) is a condition commonly associated with syncope, nearly two-thirds of older persons with OH can present with a fall without any signs of loss of consciousness.[7,8] The diagnosis of OH merely takes into account a single drop in systolic or diastolic blood pressure (DBP) after posture change, which may not provide an accurate representation of the actual blood pressure (BP) changes in those with pathological disorders of BP control.[9]

Advancements in medical technology now allow convenient recording of continuous BP with noninvasive techniques, which in turn allows for the calculation of beat-to-beat blood pressure variability (BPV).[10,11] BPV is the fluctuation or oscillation of BP that is measured throughout a period of time, and includes

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long-term (week-to-week, month-to month, or even visit-to-visit), short-term (morning-to-evening), and very short-term (beat-to-beat) variation.[12] Research into BPV is now receiving increased attention since long-term BPV has been found to be associated with increased risk of vascular events and even total mortality.[12–19] In addition, short-term BPV is also linked to all-cause mortality, increased cardiovascular events, and target organ damage among hypertensive patients.[20,21]

Continuous measurements of BP using noninvasive techniques is as accurate as invasive techniques.[10,11] A handful of studies using continuous noninvasive BP measurements have attempted to explain the morphology of BP changes with OH and falls.[8,22] There appears to be a paucity of studies into the relationship between BPV with falls. We, therefore, determined the relationship between both time-domain and frequency-domain BPV and falls for individuals aged 55 years and older.

2. Methods

2.1. Study design

The Malaysian Elders Longitudinal Research (MELoR) study is a longitudinal cohort study involving individuals aged 55 years and older selected through simple random sampling stratified by age and ethnicity from the electoral rolls of the parliamentary constituencies of Petaling Jaya Utara, Petaling Jaya Selatan, and Lembah Pantai. Recruitment was through house-to-house and postal invitation. The study also included volunteers who fulfilled the age criteria living within the geographical location. Informed consent was obtained from each individual before their inclusion. Individuals who were unable to provide informed consent were excluded. The MELoR project was approved by the University of Malaya Medical Ethics Committee (MEC Ref No: 943.6).

2.2. Baseline and continuous BP assessment

Baseline characteristics were obtained during a computer-aided interview while BP and physical parameters were captured during a hospital visit performed on a separate occasion. Accordingly, age, sex, medical history, and medications were obtained through the computer-aided interview. Body weight, height, and continuous BP measurements, and the timed up-and-go (TUG) and frailty walk (15 feet) tests were performed during the hospital-based health check. Medications were subsequently classified according to the WHO Anatomical and Therapeutic Classification system by trained pharmacists.[23]

Every individual underwent a supine-to-standing orthostatic test (active stand) with noninvasive continuous systolic (SBP) and DBP measurements obtained using the vascular unloading technique (Task Force, CNSystem, Austria).[7,9,11,24] An appropriately sized finger cuff was applied as recommended by the manufacturer. Individuals were instructed not to move the hand fitted with the finger cuff during 10-minutes supine rest and 3-minute active standing to reduce artefacts.[25] All recordings were made in a temperature-controlled, quiet environment, between the hours of 9AM and 12PM and were performed at spontaneous breathing rate.

The TUG test was carried out for individuals who were able to walk. Participants wore their normal footwear and were asked to use their normal walking aid. A 3-m walking path from a chair with arms was marked clearly with tape. Individuals were asked to sit correctly (hips all the way to the back of the seat) on a chair with arm rests. The researcher would first provide clear instructions and demonstrate the procedure before each measurement. Timing was started on the word "go" and ended when the individuals were seated correctly once again on the chair. For the 15-feet frailty walk, the time taken for participants to walk 15 feet at their usual pace was recorded. The participants were instructed to start walking several feet before the 0-feet marker and not stop walking for several feet after the 15-feet marker. The timer was started at the first foot fall immediately after crossing the 0-feet marker and stopped at the first foot fall immediately after crossing the 15-feet marker.

2.3. BPV

Continuous beat-to-beat BP recordings obtained during the active stand test were exported to the MATLAB software and analyzed using a custom written software program. Beat-to-beat SBP and DBP readings recorded were identified and separated into supine rest and active standing segments.

In the time-domain analysis of BPV, very-short-term BPV was computed as standard deviation (SD) as expressed in (1)[12–14,16,24,26,27] and root mean square of real variability (RMSRV) as expressed in (2) for both segments of SBP and DBP.[9] The standard deviation corresponds to square root of the sum of squares of differences of BP readings in relation to the mean value divided by the number of BP readings, whereas RMSRV corresponds to the root mean square of the real variability between adjacent individual BP readings.

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} \quad (1)$$

$$RMSRV = \sqrt{\frac{\sum_{i=1}^{i=n-1} (x_{i+1} - x_i)^2}{n-1}} \quad (2)$$

where x = R-R intervals and n = number of R-R intervals in the series of selected data

Power spectral analysis of each supine rest and active stand segment was performed with a fast Fourier transform (FFT) algorithm using the MATLAB software.[10,26,28] The output from FFT was divided 3 frequency ranges (very low frequency, 0.04–0.07 Hz; low frequency, 0.07–0.14 Hz and high frequency, 0.14–0.35 Hz).[12,24,27] Power spectral density (PSD) at the low frequency (LF) range and high frequency (HF) range was then calculated for each segment for each individual. LF and HF power were calculated in absolute values from the areas of the respective ranges. BP variability in spectral analysis was defined as LF power, HF power, total PSD as expressed in (3) and LF:HF ratio as expressed in (4).

$$\text{Total PSD} = \text{LF power} + \text{HF power} \quad (3)$$

$$\text{LF : HF ratio} = \frac{LF\,power}{HF\,power} \quad (4)$$

The ratio of standing BPV to supine BPV (SSR) was then computed for each individual. This derived measure represents the changes in variability from the supine position to the standing position.[9]

$$\text{Standing to Supine Ration (SSR)} = \frac{Standing\,BPV}{Supine\,BPV} \quad (5)$$

2.4. Data analysis

Statistical analysis was conducted using the SPSS 20.5 statistical software (SPSS Inc, Chicago, IL). Normally distributed continuous variables were expressed as mean ± standard deviation,

whereas discrete variables were expressed as frequencies with percentages in parenthesis. Non-normally distributed variables were expressed as median with interquartile range in parenthesis. The difference between groups was determined using the independent *t* test for normally distributed continuous variables, the χ^2 test for categorical variables, and Mann–Whitney *U* test for non-normally distributed continuous variables. Standing to supine ratio for BPV indices was logarithmically transformed to obtain normal distributions. Subsequent reported values were reverse logarithmically transformed. Multivariate analyses were conducted using logistic regression methods to adjust for potential confounding variables and to determine mediators of differences in standing SBPV, standing DBPV, and SSR for SBPV and DBPV. A *P* value $<.05$ was considered statistically significant.

3. Results

3.1. Patient characteristic

Synchronous continuous, noninvasive, beat-to-beat continuous BP signals of sufficient quality were available for 1218 individuals and were included in this study. Two hundred and fifty-six older individuals (21%) who experienced at least 1 fall in the preceding 12 months were considered the falls group. Eighty individuals (31%) from the falls group had experienced ≥2 falls within the previous 12 months. Of the 256 individuals who sustained at least 1 fall, 101 (39.4%) reported visiting a doctor after falling, 42 (16.4%) attended the emergency department, 17 (6.6%) were admitted to hospital, 68 (26.5%) reported injuries after their fall, and 24 (9.4%) sustained a fracture. Their baseline characteristics, medical history, cardiovascular drugs consumed, and hemodynamic indices at both supine rest and active standing positions are shown in Table 1.

Fallers were significantly older ($P=.007$), more likely to be female ($P=.006$), and required a longer time to complete the TUG and frailty walk test ($P\leq.001$ for both tests). Besides that, fallers were significantly more likely to have self-reported diabetes and Parkinson disease ($P=.002$ and $P=.032$ respectively), and had lower SBP and DBP at supine rest ($P=.006$ and $P=.002$ respectively). There were no significant differences in the proportion of population consuming alpha-adrenoreceptor antagonists, diuretics, beta-adrenoreceptor blockers, calcium channel blockers, and angiotensin-converting enzyme inhibitors between fallers and nonfallers.

When comparisons were made within the falls group, there were no significant differences in baseline characteristics and hemodynamic indices between individuals with 1 fall only and individuals with repeated falls. However, older individuals with repeated falls were significantly more likely to have self-reported angina ($P=.016$), hypertension ($P=.016$), and were more likely to be consuming ACE inhibitors ($P=.007$).

3.2. Supine and standing BPV

Table 2 summarizes the time and frequency domain SBPV in the supine and standing positions, comparing fallers and nonfallers in entire cohort as well as those with 1 fall and those with

Table 1

Characteristic of baseline demographics, medical history, and hemodynamic indices.

	Full cohort (n=1218)					Falls cohort				
	Nonfallers		Fallers			Fell once		Repeated falls		
Characteristic	n	Value	n	Value	*P*	n	Value	n	Value	*P*
*Age, y, median (Q1–Q3)	962	68 (62.4–73.1)	256	69 (64.0–75.3)	.007**	176	69 (64.1–74.8)	80	70 (62.9–76.2)	.697
‡Sex (male), n (%)	962	437 (45.4)	256	92 (35.9)	.006**	176	62 (36.9)	80	27 (33.8)	.623
†BMI, median (Q1–Q3)	962	25 (22.2–27.7)	256	25 (22.5–28.1)	.138	176	25 (22.3–28.1)	80	25 (22.6–28.4)	.681
†Waist to hip ratio, median (Q1–Q3)	949	0.9 (0.86–0.96)	251	0.9 (0.85–0.98)	.412	174	0.9 (0.85–0.97)	77	0.9 (0.85–0.98)	.887
¶Timed-up and go, s mean (s.d.)	948	12.1 (3.49)	245	13.18 (4.65)	<.001***	171	12.9 (4.55)	74	13.8 (4.84)	.153
¶Frailty walk, s, mean (s.d.)	947	6.0 (1.82)	245	6.8 (2.64)	<.001***	171	6.6 (2.43)	74	7.18 (3.05)	.105
Medical history, n (%)										
‡Myocardial infarction	962	65 (6.8)	256	17 (6.6)	.947	176	9 (5.1)	80	8 (10.0)	.146
‡Angina	962	41 (4.3)	256	13 (5.1)	.573	176	5 (2.8)	80	8 (10.0)	.016*
‡Diabetes	962	254 (26.4)	256	93 (36.3)	.002**	176	57 (32.4)	80	36 (45.0)	.052
‡Hypertension	962	495 (51.5)	256	138 (53.9)	.485	176	86 (48.9)	80	52 (65.0)	.016*
‡Cerebrovascular disease	962	34 (3.5)	256	16 (6.3)	.052	176	10 (5.7)	80	6 (7.5)	.577
‡Cancer	962	59 (6.1)	256	11 (4.3)	.262	176	8 (4.5)	80	3 (3.8)	.771
Taking cardiovascular drugs, n (%)										
‡Alpha-adrenoreceptor blockers (C02A/B/C)	962	25 (2.6)	256	7 (2.7)	.904	176	4 (2.3)	80	3 (3.8)	.502
‡Diuretics (C03)	962	93 (9.7)	256	30 (11.7)	.333	176	18 (10.2)	80	12 (15.0)	.271
‡Beta-adrenoreceptor blockers (C07)	962	141 (14.7)	256	43 (16.8)	.396	176	30 (17.0)	80	13 (16.2)	.875
‡Calcium-channel blockers (C08)	962	253 (26.3)	256	64 (25.0)	.674	176	38 (21.6)	80	26 (32.5)	.062
‡ Angiotensin-converting enzyme inhibitors (C09)	962	232 (24.1)	256	65 (25.4)	.673	176	36 (20.5)	80	29 (36.2)	.007**
Hemodynamic indices at supine rest, mean (s.d.)										
¶Systolic blood pressure	962	117 (19.5)	256	113 (20.2)	.006**	176	114 (20.2)	80	113 (20.3)	.649
¶Diastolic blood pressure	962	73 (15.6)	256	69 (15.8)	.002**	176	69 (15.6)	80	68 (16.4)	.505
¶Heart rate	962	69 (10.3)	256	70 (10.8)	.283	176	70 (10.5)	80	70 (11.6)	.836
Hemodynamic indices at active stand, mean (s.d.)										
¶Systolic blood pressure	962	116 (27.1)	256	114 (27.4)	.217	176	115 (26.6)	80	113 (29.1)	.582
¶Diastolic blood pressure	962	78 (19.0)	256	76 (19.5)	.133	176	77 (19.1)	80	74 (20.2)	.195
¶Heart rate	962	76 (10.9)	256	77 (12.0)	.578	176	77 (12.2)	80	77 (11.5)	.903

BMI = body mass index, Q1 = quartile 1, Q3 = quartile.

* $P<.05$.

** $P<.01$.

*** $P<.001$.

† Perform with Mann–Whitney *U* test.

‡ Perform with χ^2 independence test.

¶ Perform with independent *t* test.

Table 2

Supine and standing blood pressure variability.

BPV indices, mean (95% CI)	Full cohort			Falls cohort		
	Nonfaller (n = 962)	Faller (n = 256)	*P*	Fell once (n = 176)	Repeated fall (n = 80)	*P*
Supine						
Time domain						
SD						
SBPV	6.67 (2.70–16.43)	6.83 (2.73–17.06)	.452	6.68 (2.64–16.89)	7.16 (2.95–17.39)	.263
DBPV	4.91 (2.07–11.60)	4.91 (2.08–11.59)	.974	4.81 (2.03–11.39)	5.15 (2.20–12.02)	.237
RMSRV						
SBPV	1.84 (0.81–4.17)	1.86 (0.85–4.08)	.714	1.86 (0.90–3.88)	1.85 (0.76–4.52)	.920
DBPV	1.74 (0.63–4.79)	1.75 (0.66–4.67)	.788	1.76 (0.73–4.23)	1.74 (0.53–5.66)	.861
Frequency Domain						
LF, $mmHg^2$						
SBPV	5419 (850–34548)	5220 (720–37843)	.571	5129 (706–37424)	5426 (743–39605)	.675
DBPV	3865 (719–20766)	3525 (637–19504)	.121	3492 (606–20126)	3597 (706–18313)	.798
HF, $mmHg^2$						
SBPV	1982 (238–16463)	2097 (258–17024)	.446	2124 (288–15656)	2041 (203–20436)	.779
DBPV	1438 (160–12880)	1552 (193–12462)	.318	1566 (213– 11490)	1520 (155–14902)	.834
Total PSD, $mmHg^2$						
SBPV	12451 (2266–68417)	12558 (2203–71563)	.887	12293 (2259–66888)	13161 (2079–83318)	.562
DBPV	8533 (1537–47371)	8221 (1531–44147)	.535	8120 (1563–42915)	8446 (1452–49138)	.729
LF:HF ratio						
SBPV	2.73 (0.50–14.83)	2.49 (0.43–14.26)	.116	2.42 (0.39–15.04)	2.66 (0.56–12.52)	.416
DBPV	2.69 (0.40–17.85)	2.27 (0.35–14.83)	.011*	2.23 (0.32–15.49)	2.37 (0.42–13.19)	.641
Standing						
Time domain						
SD						
SBPV	8.09 (3.45–18.96)	7.52 (2.99–18.88)	.016*	7.61 (3.07–18.86)	7.32 (2.82–18.98)	.526
DBPV	5.65 (2.39–13.35)	5.29 (2.17–12.86)	.031*	5.37 (2.27–12.70)	5.10 (1.97–13.19)	.388
RMSRV						
SBPV	2.30 (0.94–5.63)	2.15 (0.87–5.34)	.033*	2.14 (0.96–4.78)	2.18 (0.72–6.61)	.763
DBPV	1.96 (0.67–5.74)	1.89 (0.66–5.46)	.389	1.90 (0.73–4.91)	1.89 (0.53–6.71)	.956
Frequency domain						
LF, $mmHg^2$						
SBPV	1274 (185–8736)	1038 (138–7771)	.003**	1119 (147–8507)	879 (125–6188)	.075
DBPV	740 (129–4245)	637 (100–4047)	.016*	690 (108–4430)	531 (89–3182)	.035*
HF, $mmHg^2$						
SBPV	357 (40–3186)	316 (32–3079)	.112	320 (35–2889)	307 (26–3560)	.797
DBPV	194 (22–1731)	192 (21–1721)	.905	192 (27–1378)	194 (14–2673)	.938
Total PSD, $mmHg^2$						
SBPV	2761 (482–15793)	2358 (350–15878)	.012*	2460 (381–15885)	2149 (292–15803)	.293
DBPV	1566 (284–8612)	1417 (233–8633)	.101	1457 (261–8125)	1334 (182–9790)	.469
LF:HF ratio						
SBPV	3.56 (0.60–20.99)	3.28 (0.63–17.21)	.188	3.50 (0.74–16.52)	2.86 (0.45–18.08)	.070
DBPV	3.81 (0.56–25.84)	3.31 (0.57–19.13)	.033*	3.61 (0.82–15.81)	2.74 (0.30–25.01)	.020*

Note: Antilogarithmic values were presented. CI = confidence interval, DBPV = diastolic blood pressure variability, HF = high frequency power, LF = low frequency power, LF:HF ratio = ratio of low-frequency power to high-frequency power, RMSRV = root mean square of real variability, SBPV = systolic blood pressure variability, SD = standard deviation, total PSD = total power spectral density

* $P < .05$.

** $P < .01$.

recurrent falls within the fallers cohort. No differences in supine-SBPV between fallers and non-fallers or between those with single falls and recurrent falls within the falls group. Standing-SBPV was significantly higher among nonfallers, compared to fallers using the time domain analyses of SBPV-SD ($P = .016$) and SBPV-RMSRV ($P = .033$) and frequency domain analyses of SBPV-LF ($P = .003$) and SBPV-total PSD ($P = .012$). There were no differences in standing-SBPV for HF and LF:HF ratio.

Significant differences in frequency domain DBPV-LF:HF were observed between fallers and nonfallers ($P = .011$). No significant difference in either time domain or frequency domain DBPV in the supine position was observed in fall and nonfallers as well as in those with recurrent or single falls. In the upright position, significant differences were observed between fallers and nonfallers in DBPV-SD ($P = .031$), DBPV-LF ($P = .016$), and DBPV-LF:HF ratio ($P = .033$). Whereas within the faller subgroup, significant differences in frequency domain DBPV were observed between those with a single fall compared to those with ≥2 falls in standing LF-DBPV ($P = .035$) and standing LF:HF-DBPV ($P = .020$).

3.3. SSR for BPV

Nonfallers had significantly higher SSR for SBPV-SD, SSR of SBPV-RMSRV, and SSR of SBPV-total PSD compared to nonfallers ($P = .017$, $P = .013$, and $P = .009$) respectively. Whereas the comparison within the falls subgroup showed that fallers who fell once only had significantly higher SSR of SBPV-LF:HF ratio ($P = .012$) as shown in Table 5 (Table 3).

Table 3

Standing to supine ratio of blood pressure variability.

SSR of BPV indices, mean (95% CI)	Full cohort			Falls cohort		
	Nonfaller (n = 962)	Faller (n = 256)	*P*	Fell once (n = 176)	Repeated fall (n = 80)	*P*
Time domain						
SD						
SBPV	1.21 (0.38–1.78)	1.10 (0.33–1.84)	.017*	1.14 (0.32–1.88)	1.02 (0.34–1.74)	.185
DBPV	1.15 (0.37–3.54)	1.08 (0.35–3.35)	.091	1.12 (0.37–3.36)	0.99 (0.30–3.27)	.115
RMSRV						
SBPV	1.25 (0.51–1.57)	1.16 (0.51–1.51)	.013*	1.15 (0.53–1.47)	1.18 (0.47–1.59)	.668
DBPV	1.13 (0.35–3.67)	1.08 (0.33–3.52)	.311	1.08 (0.36–3.22)	1.09 (0.28–4.22)	.923
Frequency domain						
LF, $mmHg^2$						
SBPV	0.24 (0.03–1.72)	0.20 (0.03–1.28)	.016*	0.22 (0.03–1.50)	0.16 (0.03–0.83)	.017*
DBPV	0.19 (0.03–1.12)	0.18 (0.04–0.93)	.339	0.20 (0.04–1.06)	0.15 (0.03–0.66)	.008**
HF, $mmHg^2$						
SBPV	0.18 (0.02–1.63)	0.15 (0.02–1.23)	.019*	0.15 (0.02–1.19)	0.15 (0.02–1.35)	.999
DBPV	0.14 (0.01–1.59)	0.12 (0.01–1.46)	.324	0.12 (0.01–1.22)	0.13 (0.01–2.12)	.805
Total PSD, $mmHg^2$						
SBPV	0.22 (0.04–2.49)	0.19 (0.04–2.30)	.009*	0.20 (0.04–2.25)	0.16 (0.03–2.39)	.070
DBPV	0.18 (0.03 –1.27)	0.17 (0.03–1.05)	.352	0.18 (0.03 –0.99)	0.16 (0.02–1.18)	.295
LF:HF ratio						
SBPV	1.30 (0.22–2.41)	1.32 (0.23–2.42)	.834	1.45 (0.22–2.54)	1.08 (0.25–2.07)	.012*
DBPV	1.42 (0.20–10.26)	1.46 (0.16–13.34)	.707	1.62 (0.21–12.68)	1.16 (0.10–13.75)	.025*

Note: Antilogarithmic values were presented. CI = confidence interval, DBPV = diastolic blood pressure variability, HF = high frequency power, LF = low frequency power, LF:HF ratio = ratio of low-frequency power to high-frequency power, RMSRV = root mean square of real variability, SBPV = systolic blood pressure variability, SD = standard deviation, total PSD = total power spectral density.

* $P < .05$.

** $P < .01$.

In the analyses of DBPV, none of the SSR for DBPV indices showed significant differences between nonfallers and fallers. Whereas in the faller subgroup, frequency domain indices showed that older individuals with single falls had significantly higher DBPV-LF ($P = .008$) and DBPV-LF:HF ratio ($P = .025$) compared to those with multiple falls.

3.4. Multivariate analyses for BPV

Table 4 includes the final models for time and frequency SBPV (Models 1 and 2), DBPV (Models 3 and 4), and SSR-SBPV (Models 5 and 6) with falls in the previous 12 months as the dependent variable. Both standing SBPV (RMSRV and LF power) independently associated with falls in the previous 12 months after the above adjustments (Models 1 and 2). Time domain DBPV measured with SD remained significant for falls prediction adjustments for potential confounders (Model 3), whereas the relationship between DBPV and falls in the previous 12 months was attenuated after adjustment for age, sex, diabetes, frailty walk, and supine DBP (Model 4). As for SSR for SBPV, the relationship between SSR for SBPV and falls in the previous 12 months was no longer statistically significant for both SSR-SBPV (RMSRV) time domain (Model 5) and SSR (LF SBPV) frequency domain (Model 6) once adjusted for age, sex, diabetes, frailty walk, and supine SBP.

4. Discussion

Within our cohort study which had included community-dwelling older persons aged 55 years and older, 21% of individuals experienced at least 1 fall in the past 12 months with fallers being significantly older and predominantly female. The falls characteristics within our population are therefore similar to that of previously published population-based studies.[5] Only

Table 4

Multivariate analyses for blood pressure variability.

	Dependent variables: falls in past 12 mo					
	Time domain BPV			Low-frequency BPV		
	P	Exp (B)	95% CI	*P*	Exp (B)	95% CI
Model 1 RMSRV for SBPV				Model 2 LF-SBPV		
SBPV RMSRV	.014*	0.383	0.178–0.823	LF-SBPV	.011*	0.637	0.450–0.902
Model 3—SD for DBPV				Model 4 LF-DBPV		
DBPV SD	.025*	0.410	0.187–0.896	LF- DBPV	.052	0.686	0.469–1.003
Model 5—RMSRV for SSR-SBPV				Model 6 LF SSR-SBPV		
SSR-SBPV RMSRV	.065	0.493	0.233–1.046	LF SSR-SBPV	.127	0.771	0.552–1.077

** $P < .01$. BPV = blood pressure variability, CI = confidence interval, DBPV = diastolic blood pressure variability, LF = low frequency power, RMSRV = root mean square of real variability, SBPV = systolic blood pressure variability, SD = standard deviation, SSR = supine to standing ratio. Note: Models 1, 2, 5, and 6 adjusted for age, sex, diabetes, frailty walk, and supine SBP. Models 3 and 4 adjusted for age, sex, diabetes, frailty walk, and supine DBP.

* $P < .05$.

31% of our fallers reported recurrent falls, which was lower than previously reported.[6] Gait and balance disorders represent major risk factors for falls in our cohort, with our fallers having poorer TUG scores compared to those who had not have any falls in the preceding 12 months.[4] It is, however, considered well-established that falls in older adults usually occur because of the presence of multiple combinations of risk factors.[3,4,6] Our study proposes a new risk factor for falls—reduced absolute and relative orthostatic BPV.

The concept of BPV was first brought to the attention of the scientific fraternity by Rothwell[29] in 2010 who highlighted the potential relationship between increased visit-to-visit BPV and stroke. Subsequently, increased visit-to-visit and 24-hour BPV have been found to be strongly related to cardiovascular diseases, stroke, target organ damage, and increased mortality rate.[12–18,21] Our study evaluated very-short-term BPV using noninvasive beat-to-beat BP monitoring technology, which is now considered widely available and of sufficient accuracy in terms of assessments of relative changes in BP.[11] The relevance of very-short-term BPV measured in this manner remains unclear.[12]

Short-term BPV mainly reflects the influence of central and reflex autonomic modulation and is influenced by behavioral changes such as physical activity, sleep, and postural changes.[12,29] Besides that, short-term BPV fluctuation at various frequencies occurs independently of behavior and its computations can be as simple as finding the standard deviation of BP or through a more complicated method of spectral analysis. We elected to evaluate the influence of posture change on very-short-term BPV in this study to assess its potential relevance to falls. Previous studies have only evaluated absolute BP differences in postural change with the singular objective of identifying the presence of OH, which has been linked to falls and frailty.[8,22]

In the supine position, limited differences in BPV computed using time domain or frequency domain methods between fallers and nonfallers were observed. The differences in LF to HF ratio suggests sympathetic hyporesponsiveness or potential differences in sympathovagal balance.[30] It was previously suggested that LF-DBPV is influenced by sympathetic control, whereas HF-DBPV is said to be influenced by respiration, which is known to stimulate the vagally or parasympathetically driven variations in heart rate.[31]

Differences in both time and frequency domain BPV between fallers and nonfallers became apparent in the upright posture. Falls occur if the ability of an individual to maintain their center of gravity over a stable base is compromised. The reduction in time domain DBPV and frequency domain SBPV and DBPV in fallers compared to nonfallers suggest a possible reduction in reactivity in BP control in the upright posture, which could therefore have a direct effect on susceptibility to falls. As time domain BPV and LF-DBPV are expected to predominantly be affected by sympathetic control, we may therefore further hypothesize that the reduction in SBPV and DBPV observed in the upright posture is explained by loss of sympathetic vasomotor reactivity, which may be associated with age-related conditions such as arterial stiffness or autonomic dysfunction from cerebrovascular disease.[32] We also calculated a SSR, which assesses the relative change in BPV, and this demonstrated a significantly lower increase in time domain SBPV with posture change, as well as relatively lower power spectral density for standing LF and HF SBPV compared to supine measures. Once again, this emphasizes the potential reduction in sympathetic response to standing among fallers. The supposed dose–response relationship in terms of significantly lower LF SBPV and DBPV change from supine to standing observed further supports this hypothesis. However, our study does not remove the possibility that the reduction in standing BPV does not directly lead to falls as a result of BP control, but alternatively, BPV may be a marker of underlying disease or frailty, which then leads to increased risk of falls because of either muscle weakness or reduced postural control. Indeed, this was suggested by the mediating effect of the frailty walk on the association between relative changes in SBPV while standing with falls occurrence.

Our study was limited by the medical illness of recruited individual being obtained from self-report of the presence of physician-diagnosed conditions. The consistency and reproducibility of BPV may be also questioned. However, we have tried to minimize these factors by conducting the assessments and monitoring sessions consistently in the morning, and in a temperature-controlled environment in exactly identical locations. Besides that, the computation of BPV with SSR has eliminated interindividual BPV variations, as it took into account baseline supine BPV.

5. Conclusion

In conclusion, this was the first study to report lower very-short-term standing BPV as an independent predictor of falls. Our exploratory analyses suggest a potential link between lack of response in SBPV and posture change among fallers could be explained by reduced walking speed, age, sex, diabetes, and supine SBP. Further research is needed to fully understand the relevance of very-short-term BPV in the health of the older persons, as well as to identify factors that could alter very-short-team BPV as a potentially modifiable risk factor for falls in older adults.

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