Journal of Frailty, Sarcopenia and Falls

Short Communication

Bioimpedance-Derived Phase Angle Was Associated with Faster Blood Pressure Stabilisation Following Orthostatic Challenge in Older Adults

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Abstract

Phase Angle (PA), derived from bioelectrical impedance analysis, reflects cellular health and may indicate physiological resilience in ageing. We examined the relationship between PA and blood pressure (BP) recovery following an orthostatic challenge in 107 older adults attending a specialist falls clinic. Participants underwent active stand testing with continuous, beat-to-beat BP monitoring over 180 seconds. PA was categorised into tertiles (low, medium, high), and changes in systolic (SBP) and diastolic BP (DBP) were analysed using linear mixed-effects models, adjusted for age, sex, diabetes, hypertension, and cardiovascular and psychotropic medication use. Compared to the low PA tertile, individuals in the medium and high PA tertiles demonstrated faster recovery in both SBP and DBP during the 10–20 second post-stand period (all $p < 0.001$). No significant differences were observed in recovery between the 20–30 and 30–40 second intervals. Furthermore, participants in the high PA tertile showed, in contrast to the low PA tertile, full mean BP recovery at 40 seconds, with no further upward trend thereafter ($p = 0.001$ for SBP, $p = 0.005$ for DBP). PA could be a simple, non-invasive biomarker of dynamic physiological resilience, potentially identifying older adults at increased risk of early orthostatic haemodynamic instability.

Keywords: Phase Angle, Blood Pressure, Postural Hypotension, Aged, Electric Impedance

Phase Angle (PA), derived from bioelectrical impedance analysis (BIA), is an established indicator of cellular health[1]. Lower PA values have consistently been linked to adverse age-related conditions such as sarcopenia, malnutrition, frailty, and increased mortality[2-5]. Emerging evidence also highlights significant associations between lower PA and elevated cardiovascular risk and systemic inflammation, underscoring its potential role in cardiovascular risk assessment[6,7]. Orthostatic blood pressure (BP) recovery, an indicator of dynamic neurocardiovascular resilience[8], is similarly important in ageing, with impaired recovery associated with greater risk of falls and mortality[9,10].

Given the overlap between PA and other markers of physiological resilience, it is plausible that higher PA may reflect more efficient cardiovascular adaptation to orthostatic challenge. We hypothesised that individuals with higher PA would exhibit more rapid stabilisation of systolic and diastolic BP after postural change, indicative of more resilient autonomic and cardiovascular function.

Adults aged ≥50 years were prospectively recruited between January and November 2022 at the Falls and Syncope Unit (FASU) at St. James's Hospital, Dublin, Ireland. The clinical research setting has been described in detail elsewhere[11,12]. Participants were referred for

The authors have no conflict of interest.

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Edited by: *Dawn Skelton*

Accepted *19 July 2025*

Characteristic	Low PA (n=35)	Medium PA (n=36)	High PA (n=36)	p-value
Age, mean (SD)	77.3 (8.5)	69.7 (7.0)	62.5 (9.9)	**<0.001^**
Female sex, n (%)	18 (51%)	25 (69%)	18 (50%)	0.179 #
Diabetes, n (%)	6 (17%)	4 (11%)	6 (17%)	0.729 #
Hypertension, n (%)	19 (54%)	18 (50%)	14 (39%)	0.406 #
Cardiovascular medication, n (%)	22 (63%)	19 (53%)	13 (36%)	0.074 #
Psychotropic medication, n (%)	15 (43%)	12 (33%)	7 (19%)	0.103 #

^ One-way ANOVA; # Chi-square test.

Table 1. Participant Characteristics by Phase Angle (PA) Tertile.

specialist assessment of unexplained falls, syncope, or orthostatic intolerance. Inclusion criteria required participants to provide written informed consent, mobilise independently (with or without a mobility aid), and be able to transfer independently or with minimal assistance from lying to standing. Individuals were excluded if they had contraindications to BIA, such as the presence of an indwelling electronic device (e.g., pacemaker).

Body composition was assessed using the medically accredited TANITA® DC-430MA device (Tanita Europe, Amsterdam, The Netherlands). Participants stood barefoot on the scale, having removed outerwear and emptied their pockets; a standard tare value of 0.5 kg was applied to account for clothing. Resistance (R) and reactance (Xc) measured at 50 kHz were used to calculate PA using the formula: PA = arctangent (Xc/R) × (180/π). Participants were categorised into tertiles based on PA values, and group differences were assessed using one-way ANOVA for continuous variables and chi-square tests for categorical variables.

All participants completed an active stand test following a validated protocol fully described elsewhere12. The test adhered to recommended guidelines, beginning with a 5–10 minute supine rest and signal calibration phase, after which participants were instructed to stand up as quickly as possible—using minimal assistance if required—and remain quietly standing for 3 minutes. Non-invasive, continuous, beat-to-beat systolic (SBP) and diastolic (DBP) BP were recorded using the Finapres® NOVA device (Finapres Medical Systems, Amsterdam, The Netherlands).

Demographic and clinical data, including age, sex, history of hypertension and diabetes mellitus, and medication use, were obtained from medical records. Cardiovascular medication use was coded as 'Yes' if participants were taking one or more of the following ATC-classified drugs: anti-arrhythmics (C01), anti-hypertensives (C02), diuretics (C03), vasodilators (C04), beta-blockers (C07), calcium channel blockers (C08), or agents acting on the renin–angiotensin system (C09). Psychotropic medication use was coded as 'Yes' if participants were taking anti-epileptics (N03A), anti-psychotics, anxiolytics, hypnotics or sedatives (N05), or antidepressants (N06A)[12].

Descriptive statistics and bivariate correlations between normally distributed continuous variables (using Pearson's r) were computed. Group differences in participant characteristics across PA tertiles were assessed using one-way ANOVA for continuous variables and chi-square tests for categorical variables. All these analyses were performed using IBM SPSS Statistics, version 29.0 (IBM Corp., Armonk, NY, USA).

Stata version 15.1 (StataCorp, College Station, TX, USA) was used to compute linear mixed-effects regression models to evaluate the association between PA tertiles (low, medium, high) and trajectories of SBP and DBP over the 180-second post-stand period. For this, the dataset was restructured from wide to long format, such that repeated measures for each subject were represented in multiple rows rather than in separate columns. Time was modelled as a continuous variable using restricted cubic splines[13] with knots placed at 10, 20, 30, and 40 seconds, allowing for flexibility in capturing non-linear recovery patterns particularly within the early phase of orthostatic response. Interaction terms between time splines and PA tertile were included to test whether BP recovery trajectories differed by PA group. All models included a random intercept for participant ID to account for individual-level variability and repeated measures, and a first-order autoregressive [AR(1)] residual structure was specified to address temporal autocorrelation of BP readings within participants. Covariates included in the models were age, sex, hypertension, diabetes, and cardiovascular and psychotropic medication use. Model estimates were used to calculate predicted marginal means of BP at each time point for each PA tertile using the margins command in Stata. Pairwise contrasts between tertiles at each time point were tested to identify significant group differences

Interaction Term* / Covariate	ΔSBP Coefficient (95% CI)	p-value	ΔDBP Coefficient (95% CI)	p-value
Medium PA × 0–10s	−0.43 (−0.84, −0.01)	**0.044**	−0.24 (−0.49, 0.02)	0.069
High PA × 0–10s	−0.09 (−0.51, 0.32)	0.665	0.02 (−0.23, 0.27)	0.883
Medium PA × 10–20s	1.35 (0.93, 1.77)	**<0.001**	0.83 (0.57, 1.08)	**<0.001**
High PA × 10–20s	1.71 (1.30, 2.13)	**<0.001**	1.11 (0.85, 1.36)	**<0.001**
Medium PA × 20–30s	0.19 (−0.22, 0.61)	0.367	0.22 (−0.04, 0.47)	0.092
High PA × 20–30s	0.12 (−0.30, 0.53)	0.573	0.05 (−0.20, 0.31)	0.687
Medium PA × 30–40s	−0.21 (−0.62, 0.21)	0.328	−0.13 (−0.38, 0.13)	0.327
High PA × 30–40s	−0.21 (−0.62, 0.21)	0.328	−0.09 (−0.34, 0.16)	0.498
Medium PA × >40s	−0.04 (−0.10, 0.02)	0.209	−0.02 (−0.05, 0.02)	0.360
High PA × >40s	−0.11 (−0.17, −0.05)	**0.001**	−0.05 (−0.09, −0.02)	**0.005**
Age (per year)	−0.12 (−0.36, 0.11)	0.303	−0.30 (−0.50, −0.10)	**0.003**
Sex (Male)	0.34 (−0.25, 0.92)	0.253	0.18 (−0.24, 0.59)	0.392
Diabetes	0.01 (−0.55, 0.58)	0.964	0.26 (−0.21, 0.74)	0.275
Hypertension	0.30 (−0.19, 0.78)	0.229	0.09 (−0.30, 0.48)	0.652
Cardiovascular medications	0.27 (−0.25, 0.79)	0.300	0.17 (−0.27, 0.62)	0.442
Psychotropic medications	−0.16 (−0.69, 0.38)	0.554	−0.24 (−0.69, 0.20)	0.284

** These are comparisons with the Low PA tertile.*

Table 2. Linear mixed-effects model estimates for the associations between PA tertiles and systolic (ΔSBP) and diastolic (ΔDBP) blood pressure recovery across time intervals, adjusted for covariates.

in BP recovery. Visualisation of predicted BP trajectories was performed using the marginsplot command, with 95% confidence intervals.

Statistical significance was defined as a p-value of < 0.05 throughout.

In the total sample (n = 107), PA values were grouped across tertiles (n = 35, 36, and 36). The mean PA was 3.60 degrees (SD = 0.40) in the low tertile, 4.60 degrees (SD = 0.31) in the medium tertile, and 5.83 degrees (SD = 0.64) in the high tertile. The full range of PA values was 2.77 to 7.67 degrees. In the full sample, there was a statistically significant moderate-to-strong negative correlation between age and PA (Pearson's r = −0.638, p < 0.001). Age also showed statistically significant negative correlations with systolic BP recovery at 20 seconds (r = −0.191, p = 0.048) and with diastolic BP recovery at 20 seconds (r = −0.298, p = 0.002); however, the strength of these associations was notably weaker than that observed between age and PA. Participants in higher PA tertiles were significantly younger, with mean age decreasing from 77.3 to 62.5 years (p < 0.001). No statistically significant differences were found across tertiles for sex, diabetes, hypertension, or medication use, although a non-statistically significant trend toward lower medication use with increasing PA was suggested (Table 1).

The mixed-effects models interaction analysis (Table 2) showed that compared to the low PA tertile, individuals in the medium and high PA tertiles demonstrated faster recovery in both SBP and DBP during the 10–20 second post-stand period (all p < 0.001). No significant differences were observed in recovery between the 20–30 and 30–40 second intervals. Furthermore, participants in the high PA tertile showed, in contrast to the low PA tertile, full mean BP recovery at 40 seconds, with no further upward trend thereafter (p = 0.001 for SBP, p = 0.005 for DBP). Notably, in these models, age was not a significant covariate for SBP recovery (p = 0.303), although it was significant in the diastolic model (p = 0.003). None of the other covariates reached statistical significance in either model (Table 2). Figure 1 and Figure 2 illustrate the estimated marginal means and 95% confidence intervals for changes in SBP and DBP, respectively, over 180 seconds following the active stand, across PA tertiles in fully adjusted models.

Regarding the discussion of our findings, this study examined the relationship between PA and orthostatic BP responses in older adults. Our results suggest that higher levels of PA are independently associated with more efficient early BP stabilisation following an orthostatic

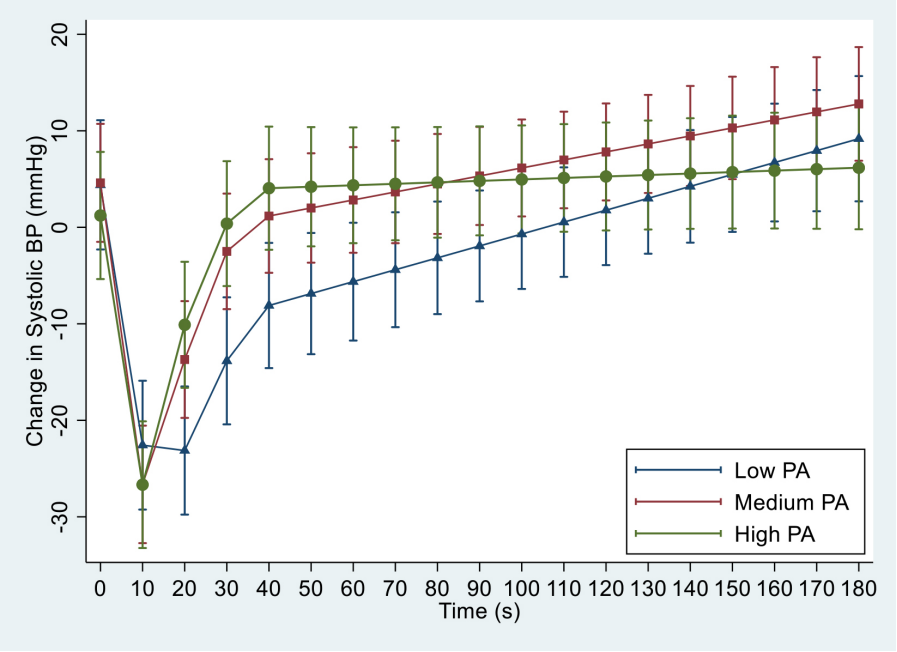

Figure 1. Estimated marginal means and 95% confidence intervals for changes in SBP over 180 seconds following the active stand, across Phase Angle (PA) tertiles in the fully adjusted model.

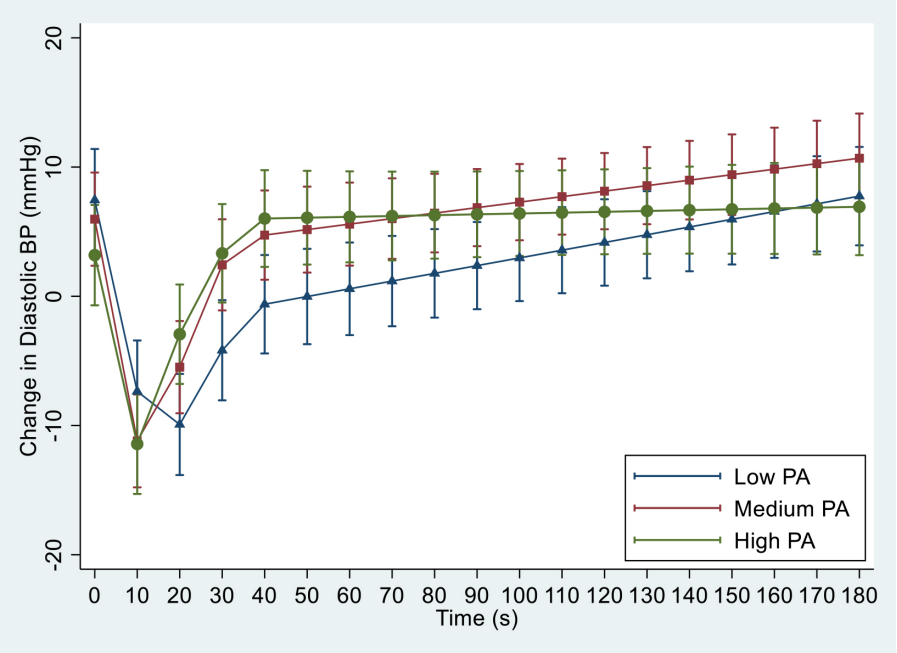

Figure 2. Estimated marginal means and 95% confidence intervals for changes in DBP over 180 seconds following the active stand, across Phase Angle (PA) tertiles in the fully adjusted model.

challenge, reinforcing its potential value as a non-invasive biomarker of physiological resilience in ageing populations.

Participants in the higher PA tertiles demonstrated significantly faster recovery of both systolic and diastolic BP within the critical 10–20 second period following standing. This early phase of orthostatic recovery is understood to reflect the integrity of autonomic reflexes, particularly baroreceptor sensitivity and vascular tone regulation[14]. Indeed, if this "transient" period resolves within 20 seconds and steady-state values approximate the normotensive baseline, a normal orthostatic response is more likely to be maintained through to 180 seconds[15]. Consistently, participants in the high PA tertile demonstrated complete mean BP recovery by 40 seconds, with no further upward trend, in significant contrast to those in the low PA group.

A previous report using the same mixed-effects models, but focusing on sarcopenia status (robust, probable sarcopenia, and sarcopenia) as predictors of orthostatic BP response, found that both probable and confirmed sarcopenia were independently associated with an attenuated rate of recovery in both systolic and diastolic BP during the 10–20 second period after standing. However, the effect sizes were somewhat smaller compared to the present analysis, which focused on PA tertiles rather than sarcopenia status. In a separate analysis of the same sample, PA showed significant bivariate associations with multimorbidity (CIRS-G), physical frailty (SHARE-FI), and BIA-confirmed sarcopenia[16]. This suggests that, while PA may reflect or fully encompass the effects of sarcopenia, it may also capture broader systemic processes related to adverse cellular health, such as hydration, oxidative stress and inflammation[17], that influence orthostatic haemodynamic responses and involve other organ systems beyond skeletal muscle, such as neurovascular tissue. Importantly, the associations remained significant after adjusting for confounders, including age—which was notably influential, as suggested in Table 1, and the only significant covariate in the mixed-effects models, though only in the diastolic model ($\beta = -0.30$, $p = 0.003$). This suggests that PA provides additional value beyond traditional risk markers and may complement existing tools for assessing orthostatic intolerance or fall risk.

Existing literature includes investigations into the potential applications of observed changes in BIA parameters during postural shifts[18-21]. However, these findings are not always consistent[22]. One study found that in older adults, poorer postural control—particularly in challenging balance positions—was significantly associated with lower BIA parameters (resistance, reactance, and PA) and reduced physical function, suggesting that BIA may be a useful marker for balance and fall risk assessment in older people[23]. However, none of these studies specifically investigated BIA or BIA-measured PA in the context of orthostatic haemodynamic responses.

While PA has been shown to correlate with cardiovascular risk scores[6,7], its association with real-time functional markers such as orthostatic BP recovery has, to our knowledge, not been previously explored. Limitations of this study include its cross-sectional design, which precludes causal inference, and a relatively small sample size, underscoring the need for external replication. Nonetheless, the biological plausibility of our findings is supported by suggested mechanisms through which PA, representing the ratio of reactance to resistance in bioelectrical impedance, reflects cell membrane integrity and body cell mass. Higher PA values indicate more intact membranes and greater intracellular water, which are hallmarks of healthier tissue. This cellular integrity may facilitate more efficient autonomic signalling, vascular tone regulation, and cardiac performance during orthostatic stress. Thus, PA may serve as an indirect indicator of the physiological resilience required for prompt cardiovascular adaptation to standing. We also note that age was a significant covariate in our DBP analysis, underscoring its important role in shaping physiological responses to orthostatic challenge and its close relationship with PA. However, our data suggest that age alone does not fully account for these responses, indicating that PA may capture additional, age-independent aspects of physiological function. However, our observational design, along with the lack of data on blood volume or hydration status, inflammatory markers, and other potential mediators such as autonomic nervous function, including arterial baroreflex sensitivity, highlights the need for further research to clarify these pathways.

In conclusion, this study provides novel evidence that higher PA is associated with more robust early orthostatic BP recovery in older adults. These findings highlight the potential of PA as a simple, non-invasive marker for identifying older individuals at risk of orthostatic hypotension-related falls and for evaluating the effects of interventions aimed at mitigating this risk.

Ethics approval

The study received ethical approval from the Tallaght University Hospital (TUH)/ St. James's Hospital (SJH) Joint Research Ethics Committee (Project ID: 0221; approval date: 4 May 2021). Approval was also granted by St. James's Hospital Research & Innovation Office (Reference: 6567, approval date: 26 July 2021). This study was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its subsequent amendments.

Consent to participate

All participants provided written informed consent for inclusion in the study.

Funding

This research was funded by Research Ireland, grant number 18/FRL/6188.

Authors' contributions

Roman Romero-Ortuno conceived and designed the study and drafted the manuscript. Eoin Duggan acquired and interpreted data and critically revised the manuscript. Both authors approved the final version and agreed to be accountable for all aspects of the work, ensuring that questions related to its accuracy or integrity are appropriately investigated and resolved.

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