

ORIGINAL ARTICLE

Standing orthostatic blood pressure measurements cannot be replaced by sitting measurements

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As many elderly patients are not able to stand for several minutes, sitting orthostatic blood pressure (BP) measurements are sometimes used as an alternative. We aimed to investigate the difference in BP response and orthostatic hypotension (OH) prevalence between the standard postural change to the sitting and the standing position in a cross-sectional observational study. BP was measured with a continuous BP measurement device during two postural changes, from supine to the sitting and from supine to the standing position. Linear mixed models were used to investigate the differences in changes (Δ) of systolic BP (SBP) and diastolic BP (DBP) between the two postural changes. The prevalence and the positive and negative proportions of agreement of OH were calculated of the two postural changes. One hundred and four patients with a mean age of 69 years were included. Δ SBP was significantly larger in the standing position compared with the sitting between 0 and 44 s. Δ DBP was significantly larger in the sitting position compared with the standing 75–224 s after postural change. The prevalence of OH was 66.3% (95% confidence interval (CI) 57.2, 75.4) in the standing position and 67.3% (95% CI 58.3, 76.3) in the sitting position. The positive proportion of agreement was 74.8% and the negative proportion of agreement was 49.3%. A clear difference was seen in BP response between the two postural changes. Although no significant difference in prevalence of OH was observed, the positive and negative proportion of agreement of the prevalence of OH were poor to moderate, which indicates a different outcome between both postural changes.

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INTRODUCTION

Orthostatic hypotension (OH) is a key manifestation of hemodynamic dysfunction observed when adaptive mechanisms fail to compensate for a sudden reduction in venous return during active postural change.^{1,2} The postural change leads to pooling of blood in the pelvis and lower extremities caused by gravity. Counteracting circulatory mechanisms lead to an increase in heart rate (HR) and peripheral vasoconstriction and result, in combination with the skeletal muscle pump, in an increase of venous return.^{3,4} The prevalence of OH rises with age,^{5,6} varying from 12% to 18% in community-dwelling elderly^{7,8} and from 37% to >50% in nursing home residents.^{9,10}

The international consensus definition recommends continuous beat-to-beat blood pressure (BP) measurements to diagnose OH,¹¹ and orthostatic BP is advised to be measured in the standing position after 5 min of rest in the supine position.¹¹ However, as many elderly patients are not able to stand for several minutes, sitting orthostatic BP measurements are sometimes used as an alternative.⁹ The prevalence of seated OH was described in the review of Gorelik and Cohen¹² and varied from 8% in community-dwelling individuals

to 56% in elderly hospitalized patients. They conclude that seated OH should be assessed in patients unable to stand. None of the studies described in the review compared seated *vs.* standing OH measurement.

Differences in prevalence of OH measured either in the standing or the sitting position are unknown in the elderly population. Therefore, we aimed to investigate the difference in BP response and prevalence of OH between two different postural changes: standing *vs.* sitting.

METHODS

Study population

For this cross-sectional observational study, patients were recruited from the outpatient clinic of internal medicine (Isala Hospital, Zwolle, the Netherlands). Inclusion criteria were adults aged >50 years combined with a medical history of one or more of the following diseases: cardiovascular disease, diabetes mellitus, and hypertension. Exclusion criteria were the inability to perform BP measurements at one arm, inability to stand without assistance, known peripheral vessel disease in one or both arms, needing a large (≥ 42 cm) or small (≤ 28 cm) upper arm cuff and incapability of giving consent. We aimed to include at least 100 elderly patients. Patients were non-blinded randomized for both the

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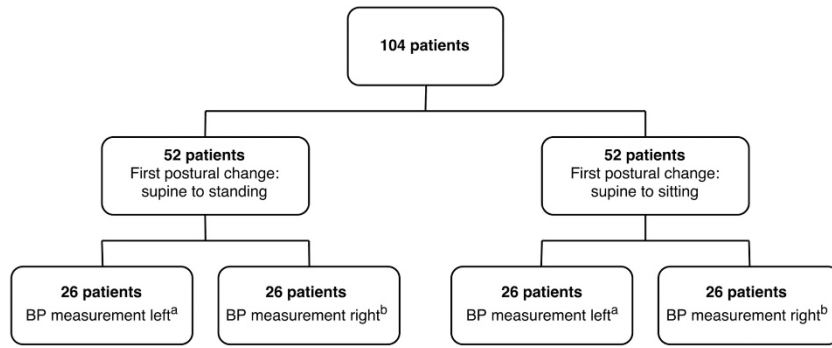


Figure 1 Randomization. ^aContinuous BP measurement device on the left arm. ^bContinuous BP measurement device on the right arm.

sequence of the postural changes and the side of the BP measurements. By randomizing the BP measurements on the left and right arm, we tried to minimize the influence of the side on the BP response and the prevalence of OH. The randomization was performed in blocks of four (Figure 1).

Data collection

Baseline data included demographic characteristics and a full medical history, including a history of cardiovascular disease, diabetes mellitus, hypertension, polyneuropathy, Parkinson's disease, pacemaker implantation, falls in the previous year and medication use. A history of cardiovascular disease was defined as a history of angina pectoris, myocardial infarction, percutaneous transluminal coronary angioplasty, coronary artery bypass grafting, stroke and/or transient ischemic attack.

All measurements were performed by one of the authors (ACB). Each participant performed both postural changes in a crossover design (supine to standing and supine to sitting) and remained in those positions for at least 4 min. Prior to the postural change, baseline BP was measured in the supine position after 5 min of rest. BP was measured with the Finometer Pro (Finapres Medical Systems BV, Enschede, the Netherlands), a continuous non-invasive beat-to-beat BP measurement device, which has previously been validated compared with invasive BP recordings.^{13,14} Finger circumference was measured to apply the proper sized finger cuff of the Finometer Pro.¹⁵ In addition, height differences were corrected by a height nulling procedure and by supporting the finger cuff at heart level during the whole procedure.^{15,16} During the measurements, correct positioning of the arm was repeatedly checked. The Finometer Pro was calibrated approximately 3 min before each postural change using the return-to-flow calibration system, which monitors the finger pressure distal of an occluding upper arm cuff to align the finger BP to brachial BP.¹⁵ The presence of characteristic symptoms of OH such as dizziness, blurred vision or light-headedness was asked.

BP measurement data of the Finometer Pro were exported with the BeatScope software (Finapres Medical Systems BV). By measuring the arterial finger pressure, cardiac output (CO) was calculated with the use of the model flow method.¹⁷ Baseline mean supine systolic blood pressure (SBP), diastolic blood pressure (DBP), HR and CO were calculated over the last minute prior to each postural change. After postural change, the lowest SBP and DBP values were recorded, and the mean HR and CO values were calculated over eight different timeframes (0–14, 15–44, 45–74, 75–104, 105–134, 135–164, 165–194 and 195–224 s). Records with poor quality signals (for example, artefacts) were excluded by visual inspection of the graphics in the BeatScope output files.

OH was defined as a drop in SBP of ≥ 20 mm Hg or a drop in DBP of ≥ 10 mm Hg within 3 min after postural change,¹⁸ excluding the first 15 s. Initial OH (IOH) was defined as a drop in SBP of ≥ 40 mm Hg and/or a drop in DBP of ≥ 20 mm Hg within the first 15 s after postural change accompanied by orthostatic complaints.^{1,19}

End points

The primary end points were the differences in change of SBP and DBP between the two postural changes (supine to sitting *vs.* supine to standing). Secondary end points were the difference in change of CO and HR and the

difference in prevalence and proportions of agreement of OH, IOH and orthostatic complaints between the two postural changes.

Statistical analysis

Continuous variables were presented as mean and s.d. for normally distributed variables or as median and interquartile range for non-normally distributed variables. Categorical variables were presented as proportions. Q-Q plots and histograms were constructed to examine deviations of normality.

The difference in SBP, DBP, HR and CO between the supine and the sitting or standing position at each timeframe was defined as change (Δ). Linear mixed models (with timeframe nested within posture) were performed to investigate the differences in Δ SBP, Δ DBP, Δ HR and Δ CO at each particular timeframe between the two postural changes. The differences between both postural changes at each timeframe were tested using the Bonferroni correction for multiple testing. In addition, linear mixed models adjusted for the sequence (sitting–standing or standing–sitting) and the period (first or second measurement) were used to compare the area under the curve (AUC) of the sitting and standing SBP, DBP, HR and CO curves. Evaluating the AUC is a better method compared with single clinical BP measurements to determine the hemodynamic state in hypertensive subjects.²⁰ Additionally, the differences in prevalence of OH, IOH and orthostatic complaints according to the postural change were analyzed with McNemar tests. The positive and the negative proportions of agreement were calculated.²¹ The positive proportion of agreement is the number of both postural changes that diagnosed OH divided by the total number of OH diagnosed for each of the postural changes. The negative proportion of agreement is the number of both postural changes that excluded OH divided by the total number of excluded OH for each of the postural changes. Both positive and negative proportions of agreement are reported as percentages.

All tests were two-sided and the *P*-values were considered to be significant at *P* < 0.05. Statistical analyses were performed using the SPSS software (version 23; IBM, Armonk, NY, USA). The corresponding author had full access to all the data in the study and assumes responsibility for the accuracy and completeness of the data and all the analyses.

Ethical approval and clinical trial registration

This study was approved by the local medical ethics committee of Isala (number 15.06.95) and was performed in accordance with the declaration of Helsinki. Written informed consent was obtained from each participant during their scheduled appointment. All data were analyzed anonymously. The 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE) statement was used to describe this observational cohort study.²² The study was registered at www.trialregister.nl (NTR5525).

RESULTS

The inclusion and all study procedures were performed in January and February 2016. A total of 104 patients were included in the present study (Figure 2). Reasons to exclude patients due to measurement problems consisted of failing to find a HR on the finger cuff (*n* = 11) and unavailability of a proper sized cuff (*n* = 12). Baseline

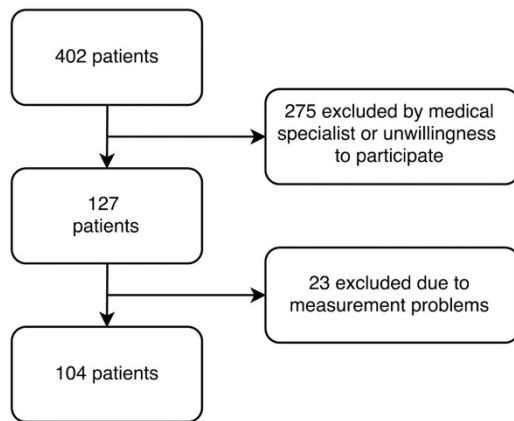


Figure 2 Patient selection.

Table 1 Baseline characteristics

| | Patients (n = 104) |
|-------------------------------------|----------------------------------|
| <i>Characteristics</i> | |
| Age (years) | 68.8 (8.5) ^a |
| Female | 45 (43) |
| BMI (kg m ⁻²) | 27.0 (24.7–31.7) ^b |
| <i>Medical history</i> | |
| Hypertension | 82 (79) |
| DM | 64 (62) |
| History of CVD | 38 (37) |
| Polyneuropathy | 33 (32) |
| Parkinson's disease | 0 (0) |
| Pacemaker implantation | 8 (8) |
| History of falls | 31 (30) |
| <i>Medication</i> | |
| Antihypertensive medication | 86 (83) |
| Antiarrhythmic medication | 6 (6) |
| Nitrates | 13 (13) |
| Oral glucose-lowering therapy | 32 (31) |
| Insulin | 52 (50) |
| Psychiatric medication | 13 (13) |
| Antiparkinsonian medication | 1 (1) |
| <i>Measurements</i> | |
| Lying SBP (mm Hg) | 150.3 (137.3–162.9) ^b |
| Lying DBP (mm Hg) | 76.7 (9.2) ^a |
| Lying HR (beats min ⁻¹) | 67.6 (60.4–73.8) ^b |
| Lying CO (l min ⁻¹) | 6.2 (1.2) ^a |
| Drinking and/or eating | 63 (61) |

Abbreviations: BMI, body mass index; CO, cardiac output; CVD, cardiovascular disease; DBP, diastolic blood pressure; DM, diabetes mellitus; HR, heart rate; SBP, systolic blood pressure. Values are presented as *n* (%), unless indicated otherwise.

^aMean (±s.d.).

^bMedian (p25–75).

characteristics of the study population are presented in Table 1. In this cohort, 104 patients (59 men, 45 women) with a mean age of 68.8 years (s.d. 8.5) were included. Baseline characteristics of patients with the first postural change to the sitting position and patients with the first postural change to the standing position and patients with the Finometer on the left arm and patients with the Finometer on the right arm are presented in Supplementary Table S1.

Postural change and hemodynamic changes

The results of the linear mixed models are presented in Table 2 and illustrated in Figure 3.

ΔSBP was significantly larger in the standing position compared with that in the sitting with -11.5 (95% confidence interval (CI) -17.0 , -5.9) and -8.7 (95% CI -14.2 , -3.2) mm Hg between 0 and 44 s ($P < 0.001$). Besides, ΔDBP was significantly larger in the sitting position compared with that in the standing 75–224 s after postural change, with 4.1 (95% CI 1.4, 6.9), 3.3 (95% CI 0.6, 6.0), 4.5 (95% CI 1.8, 7.2), 4.3 (95% CI 1.6, 7.0) and 4.4 (95% CI 1.7, 7.1) mm Hg ($P < 0.05$). In standing position, ΔHR was larger compared with the sitting position at all timeframes after postural change ($P < 0.001$), difference in Δ ranged from 4.5 to 8.1 beats min⁻¹. Sitting ΔCO was smaller compared with standing ΔCO for all timeframes (difference in Δ ranged from -0.4 to 0.7 l min⁻¹), except during first 14 s, in which sitting ΔCO was higher than standing ΔCO (difference in Δ -0.7 l min⁻¹ (95% CI -1.1 , -0.4 ; $P < 0.001$; Table 2). Owing to the possible influence of the very elderly patients and the usage of an alpha-blocker, two *post hoc* analyses were performed. Almost similar differences in hemodynamic values during all timeframes were seen (Supplementary Table S2).

Both the AUC of SBP ($P = 0.023$) and CO ($P = 0.001$) were larger, while the AUC of DBP ($P = 0.002$) and HR ($P < 0.001$) were smaller in the sitting position, all compared with the standing position (Figure 3).

Prevalence of OH, IOH and orthostatic complaints

The prevalence of OH was 66.3% (95% CI 57.2, 75.4) in the standing position and 67.3% (95% CI 58.3, 76.3) in the sitting position. In 52 out of all 104 patients, OH was diagnosed in both postural changes. The positive proportion of agreement was 74.8% and the negative proportion of agreement was 49.3%. IOH was present in 5.8% (95% CI 1.3, 10.3) and 16.3% (95% CI 9.2, 23.4) in the sitting and standing position, respectively ($P = 0.013$). The positive proportion of agreement was 26.1% and the negative proportion of agreement was 90.8%. Orthostatic complaints were reported in 13 patients (12.5%, 95% CI 6.1, 18.9) in the sitting position and in 23 patients (22.1%, 95% CI 14.1, 30.1) in the standing position ($P = 0.021$). The positive proportion of agreement was 55.6% and the negative proportion of agreement was 90.7%.

DISCUSSION

Standing resulted in a greater SBP decrease compared with sitting, whereas the opposite was observed for DBP. Although no significant difference in the prevalence of OH was observed, the positive and negative proportions of agreement of the prevalence of OH were at best moderate, indicating that a diagnosis of OH is highly dependent on the postural change.

Postural change and hemodynamic changes

It is known that by changing positions from supine to the sitting or the standing position, hemodynamic adaptive mechanisms are activated owing to the sudden decrease in BP.^{3,23–25} As seen in the sitting and the standing curves, SBP changed differently between the two positions at several timeframes, although the shape of both curves appears fairly similar. The decrease in SBP was higher in the standing position compared with that in the sitting at the first two timeframes, which could be explained by the larger hydrostatic effects in the standing position. Owing to the loss of elastin fibers and consequently less compliance and elasticity in patients with atherosclerosis and thence increased arterial stiffness caused by for instance hypertension

Table 2 Mean sitting and standing Δ SBP, Δ DBP, Δ HR and Δ CO per timeframe in all patients

| Timeframe | Systolic blood pressure (mm Hg) ^a | | | Diastolic blood pressure (mm Hg) ^a | | |
|-----------|----------------------------------------------------|------------------------------|-------------------------------------------|----------------------------------------------------|------------------------------|-----------------------------------------|
| | Sitting Δ^b (95% CI) | Standing Δ^c (95% CI) | Difference in Δ | Sitting Δ^b (95% CI) | Standing Δ^c (95% CI) | Difference in Δ |
| 0–14 s | 30.3 (27.4, 33.2) | 41.8 (38.9, 44.7) | -11.49 (-17.01, -5.96)^d | 19.4 (18.1, 20.8) | 20.1 (18.7, 21.4) | -0.65 (-3.36, 2.06) |
| 15–44 s | 17.7 (14.8, 20.6) | 26.4 (23.5, 29.3) | -8.72 (-14.24, -3.19)^d | 9.8 (8.4, 11.2) | 7.8 (6.4, 9.1) | 2.02 (-0.69, 4.73) |
| 45–74 s | 15.2 (12.3, 18.1) | 19.5 (16.6, 23.4) | -4.31 (-9.84, 1.21) | 6.6 (5.2, 7.9) | 4.0 (2.7, 5.4) | 2.55 (-0.16, 5.26) |
| 75–104 s | 12.9 (10.0, 15.7) | 12.3 (9.4, 15.2) | 0.53 (-5.00, 6.05) | 5.2 (3.9, 6.6) | 1.1 (-0.3, 2.5) | 4.14 (1.43, 6.85)^d |
| 105–134 s | 13.2 (10.3, 16.1) | 12.0 (9.1, 14.9) | 1.22 (-4.31, 6.74) | 5.0 (3.7, 6.4) | 1.8 (0.4, 3.1) | 3.29 (0.58, 6.00)^e |
| 135–164 s | 13.1 (10.2, 16.0) | 9.1 (6.2, 12.0) | 4.02 (-1.51, 9.54) | 6.1 (4.7, 7.4) | 1.6 (0.2, 3.0) | 4.46 (1.75, 7.17)^d |
| 165–194 s | 13.2 (10.3, 16.1) | 9.4 (6.5, 12.3) | 3.76 (-1.77, 9.28) | 5.8 (4.5, 7.2) | 1.5 (0.1, 2.9) | 4.33 (1.62, 7.04)^d |
| 195–224 s | 11.7 (8.9, 14.6) | 7.6 (4.7, 10.5) | 4.14 (-1.38, 9.66) | 4.9 (3.6, 6.3) | 0.5 (-0.9, 1.9) | 4.43 (1.72, 7.14)^d |
| | Heart rate (beats min ⁻¹) ^a | | | Cardiac output (l min ⁻¹) ^a | | |
| 0–14 s | -7.2 (-8.2, -6.3) | -11.7 (-12.6, -10.7) | 4.45 (2.70, 6.21)^d | -1.00 (-1.18, -0.83) | -0.28 (-0.45, -0.10) | -0.73 (-1.06, -0.39)^d |
| 15–44 s | -2.1 (-3.0, -1.1) | -9.3 (-10.2, -8.3) | 7.23 (5.48, 8.98)^d | -0.09 (-0.27, 0.09) | 0.56 (0.38, 0.74) | -0.65 (-0.98, -0.31)^d |
| 45–74 s | -1.3 (-2.3, -0.4) | -9.4 (-10.4, -8.5) | 8.10 (6.35, 9.86)^d | 0.24 (0.06, 0.42) | 0.71 (0.53, 0.89) | -0.47 (-0.83, -0.16)^d |
| 75–104 s | -1.1 (-2.0, -0.1) | -8.7 (-9.7, -7.8) | 7.67 (5.92, 9.43)^d | 0.27 (0.10, 0.45) | 0.73 (0.56, 0.91) | -0.46 (-0.79, -0.13)^d |
| 105–134 s | -1.6 (-2.6, -0.7) | -8.9 (-9.9, -8.0) | 7.29 (5.54, 9.05)^d | 0.27 (0.09, 0.44) | 0.65 (0.48, 0.83) | -0.39 (-0.72, -0.05)^e |
| 135–164 s | -1.6 (-2.6, -0.7) | -9.1 (-10.0, -8.1) | 7.47 (5.72, 9.22)^d | 0.19 (0.10, 0.36) | 0.57 (0.40, 0.75) | -0.39 (-0.72, -0.05)^e |
| 165–194 s | -1.2 (-2.1, -0.2) | -8.1 (-9.1, -7.2) | 6.97 (5.22, 8.72)^d | 0.20 (0.02, 0.37) | 0.61 (0.43, 0.79) | -0.41 (-0.75, -0.08)^e |
| 195–224 s | -0.8 (-1.7, 0.2) | -8.0 (-8.9, -7.0) | 7.21 (5.45, 8.96)^d | 0.24 (0.06, 0.41) | 0.59 (0.41, 0.77) | -0.35 (-0.69, -0.02)^e |

Abbreviations: CI, confidence interval; Δ CO, changes in cardiac output; Δ DBP, changes in diastolic blood pressure; Δ HR, changes in heart rate; Δ SBP, changes in systolic blood pressure. Values are presented as *n* (%), unless indicated otherwise.

^aTested with linear mixed models.

^bMean lying BP minus BP at single timeframes in sitting position.

^cMean lying BP minus BP at single timeframes in standing position.

^dSignificant at *P* < 0.001 (Bonferroni corrected).

^eSignificant at *P* < 0.05 (Bonferroni corrected).

or diabetes,^{26,27} the compensation for the larger hydrostatic effects could be delayed.²⁸ Moreover, a relation between hypertension and an increase in SBP after postural change has been described.^{29,30}

Although the DBP curves showed a similar trend, the decrease in DBP was larger in the sitting position compared with that in the standing at the last five timeframes after postural change. As muscle activity in the sitting position is almost 2.5 times lower compared with the standing,³¹ the lower DBP could be a physiological effect from reduced activation of the skeletal muscle pump. Subsequently, a lower muscle activity can result in a reduced peripheral vascular resistance and a fall in DBP.³²

Postural change resulted in an increased HR and an increase in CO, which subsequently was followed by a decrease in CO. HR was higher and CO was lower in the standing position compared with that in the sitting after postural change. This reaction could be explained by the response to the larger hydrostatic effects in the standing position compared with that in the sitting position and thereby a decreased venous return.³³ This postural response of HR was previously described in elderly.²⁵

Prevalence of OH, IOH and orthostatic complaints

All the above-mentioned BP differences did not result in an overall difference in the prevalence of OH between the sitting and the standing postural change. Nevertheless, although prevalence was similar in both postural changes, the positive proportion of agreement of the prevalence of OH was only 75% in the present study. This indicates that 75% of the subjects with OH were diagnosed with OH in both postural changes. The negative proportion of agreement of the prevalence of OH was 49%. Although the proportion of agreement is highly useful in clinical practice, no standard references for high or low proportion of agreement are described.²¹ In our opinion, a positive proportion of 75% is moderate and a negative proportion of 49% is low, which indicates that the different outcome between both postural changes is relevant. No differences in baseline characteristics were seen between patients with OH in the standing position compared with patients with OH in the sitting position. As the hemodynamic response is different in postural change to

standing compared with sitting position, it explains the disagreement in prevalence of OH between both postural positions.

The prevalence of IOH and orthostatic complaints were significantly higher after the postural change to the standing position. The higher prevalence of IOH and orthostatic complaints in the standing position compared with the sitting position could be explained by the larger decrease in standing SBP in the first timeframe after postural change. The prevalence of standing IOH in the present study of 16.3% was low compared with a previous published study, in which a prevalence of 58% was reported.³⁴ The difference in prevalence was probably caused by the higher age in the previous study (80.6 vs. 68.8 years). In a previous study concerning a group of patients with OH, the prevalence of orthostatic complaints was comparable to the results in the present study.⁷ The positive proportion of agreement for IOH and orthostatic complaints were both poor, which indicates that different patients were diagnosed with IOH or orthostatic complaints between the two postural changes.

Strengths and limitations

In the present study, several strengths can be mentioned. As far as we know, this is the first study investigating the difference in hemodynamic response between the sitting and the standing postural change. Linear mixed models are highly reliable in comparing hemodynamic parameters over multiple timeframes,³⁵ and all measurements were performed by the same individual. Furthermore, all patients were non-blinded randomized for both the sequence of the postural changes and the side of the BP measurements. Finally, we controlled our results by excluding octogenarians or patients using an alpha-blocker in the subgroup analyses, but this has not changed our conclusions. Limitations of our study are the small study sample and the possibility of selection bias. Owing to the fact that the patients included in this study had to be able to stand for 5 min without assistance, the study group was slightly biased compared with the more vital visitors of the outpatient department and the results are, of course, only useful in patients who are able to stand. Another limitation could be the influence of atherosclerosis on the BP measurements by using of the Finometer Pro. However, we were

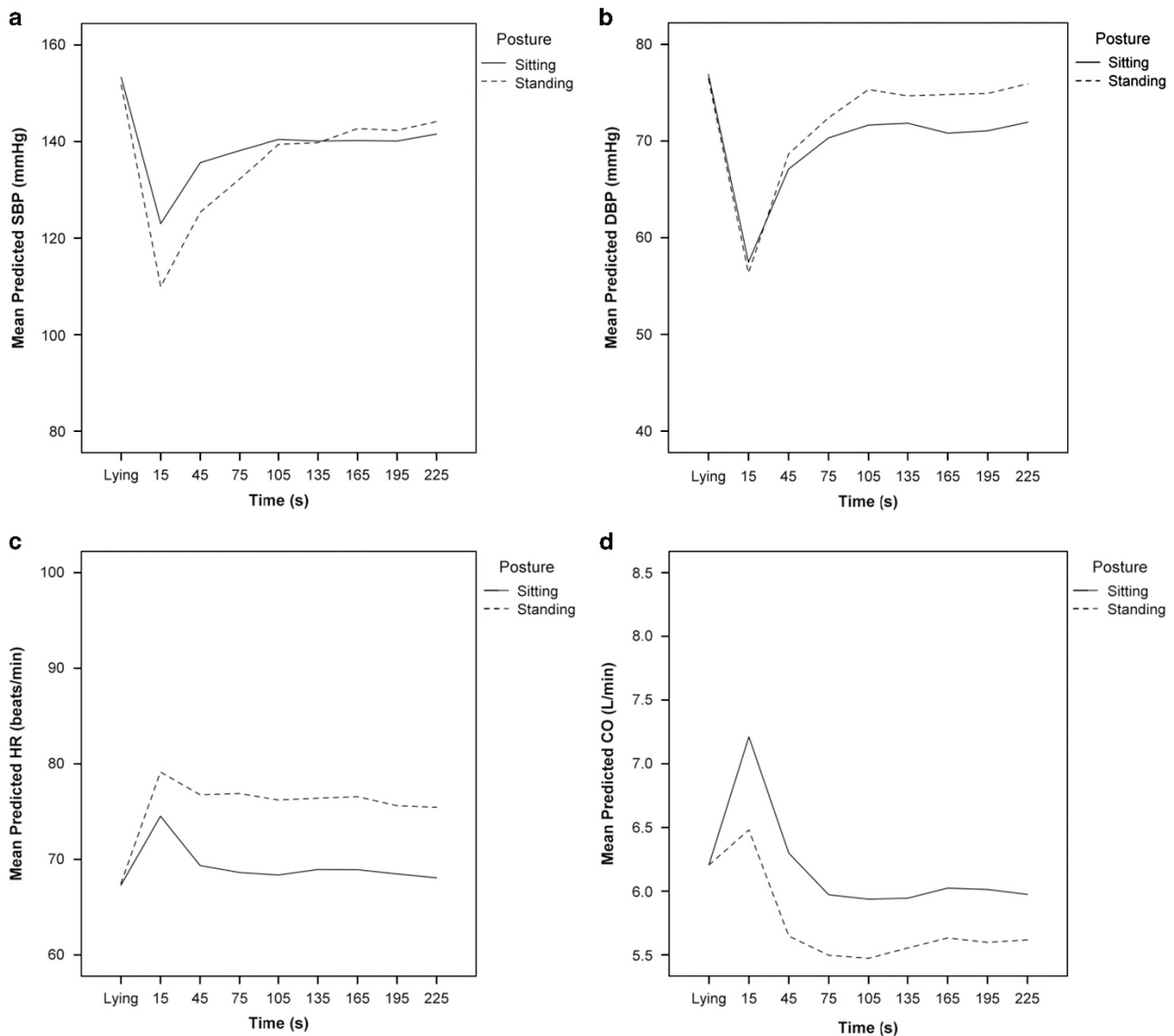


Figure 3 SBP (a), DBP (b), HR (c) and CO (d) classified in postural change as predicted by linear mixed models.

interested in the differences in hemodynamic values between the two postural changes, and for this the accuracy of the BP measurements was less important (the accuracy is the same for both postural changes). Also, two types of measurement problems can be mentioned. First, estimating CO with the model flow method in the Finometer Pro has previously been questioned and is therefore not completely reliable.³⁶ Second, delayed standing or sitting in patients with mobility problems subsequently affected the first period of continuous BP recordings after postural change and thereby the prevalence of IOH and the overall curves. Finally, the visual inspection of the graphics was performed by one author.

CONCLUSION AND PERSPECTIVES

A clear difference was seen in BP response between the two postural changes. Standing resulted in a greater SBP decrease compared with sitting, whereas the opposite was observed for DBP. Although no difference in the prevalence of OH was observed, the positive and negative proportion of agreement of the prevalence of OH were poor to moderate, which indicates relevant differences in the diagnosis of

OH depending on the postural change. It is advisable to perform OH measurements only in accordance with the consensus statement to standing position.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Supplementary Information accompanies the paper on Hypertension Research website (<http://www.nature.com/hr>)