Influence of Correction for Within-Person Variability in Blood Pressure on the Prevalence, Awareness, Treatment, and Control of Hypertension

Olaf H. Klungel, Anthonius de Boer, Arsenio H.P. Paes, Nico J.D. Nagelkerke, Jacob C. Seidell, and Albert Bakker

We assessed the influence of correction for within-person variability (WPV) on the prevalence, awareness, treatment, and control of hypertension. Data were collected from two cross-sectional population-based studies on cardiovascular disease risk factors from 1987 to 1995 among 56,026 subjects aged 20 to 59 years. Correction factors were calculated from an internal reproducibility study among 924 subjects who were examined in 1989 and 1990. The prevalence of hypertension without a correction of blood pressure values for WPV was substantially overestimated (38%), whereas the prevalence of awareness and treatment of hypertension were substantially underestimated (−13% and −28%). The prevalence of control of hypertension did not change much after this correction. It may be advisable to perform a correction for within-person variability to obtain valid prevalence estimates in surveys that only take one or two measurements of blood pressure.


KEY WORDS: Within-person variability, correction, blood pressure, prevalence, awareness, treatment, control.
MATERIALS AND METHODS

Data From Screening Project  The data reported in this study were collected from 'The Monitoring Project on Cardiovascular Risk Factors' (1987–1992), continued from 1993 to 1995 as the ‘MORGEN’ project (Monitoring Risk Factors and Health in The Netherlands). From 1987 to 1995, about 55,000 men and women aged 20 to 59 years were examined. Using a random zero sphygmomanometer, blood pressure was measured with the subject in a sitting position. Trained technicians, who all received repeated instructions and who were initially all trained by the same physician, conducted the measurements. Systolic blood pressure (SBP) was recorded at the appearance of sounds (first-phase Korotkoff), and the diastolic blood pressure (DBP) at the disappearance of sounds (fifth-phase Korotkoff). After the first measurement, the heart rate was measured for 30 s, followed after 5 min by a second blood pressure measurement.

Data From Internal Reproducibility Study  Within-person variability of blood pressure was assessed with repeated measurements of blood pressure from a random sample of the first screening project of 924 subjects who were examined in 1989 and 1990. In both years, two blood pressure measurements were performed on each individual. A nested random effects analysis of variance (SAS version 6.10, SAS Institute, Cary, NC) was used to estimate the within-person variances. The within-person variance of blood pressure was assessed with the subject in a sitting position. Trained technicians, who all received repeated instructions and who were initially all trained by the same physician, conducted the measurements. Systolic blood pressure (SBP) was recorded at the appearance of sounds (first-phase Korotkoff), and the diastolic blood pressure (DBP) at the disappearance of sounds (fifth-phase Korotkoff). After the first measurement, the heart rate was measured for 30 s, followed after 5 min by a second blood pressure measurement.

Correction for Within-Person Variability  The true distribution of blood pressure in the population could in theory be approximated by taking the average of a large number of measurements on each individual in theory be approximated by taking the average of a large number of visits. From equation 1 it can easily been shown that when the number of measurements (m) and visits (v) becomes larger, the influence of the within-person variance on the observed variance of blood pressure in the population becomes smaller.

\[
(s_{\text{obs}}^2) = (s_i^2) + (s_{\text{wb}}^2)/v + (s_{\text{ww}}^2)/vm \quad (1)
\]

where \(s_{\text{wb}}\) and \(s_{\text{ww}}\) denote the between-person, within-person-between-visit, and within-person-within-visit variances, respectively. The influence of within-person variance on the observed variance in the population can be diminished by a correction of each individual’s DBP and SBP according to equation 2.

\[
\text{BP}_i^* = \text{BP}_g + (\text{BP}_i - \text{BP}_g)(s_b/s_{\text{obs}}) \quad (2)
\]

where \(\text{BP}_g\) denotes the average blood pressure of the group, and \(\text{BP}_i^*\) and \(\text{BP}_i\) denote the corrected and uncorrected blood pressure values, respectively, for the participant. The correction factor \(s_b/s_{\text{obs}}\) can be obtained by rearranging equation 1. This correction was performed after stratification for gender, 10-year age category, and treatment status. The correction factor was calculated with equation 1, by filling in the observed variance of blood pressure in our population, and the within-person variance that was obtained from the internal reproducibility study. The correction factors were calculated for the number of visits and measurements per visit that were used in our study (one and two, respectively). We obtained 95% confidence intervals using Fisher’s Z-transformation. For each individual in the screened population from 1987 to 1995, the SBP and DBP values were corrected for WPV by using equation 2. Age- and gender-specific (10-year categories) correction factors were used, because the components of within-person variance showed some variation with age and gender. The distribution of blood pressure values corrected for WPV was used to calculate the corrected prevalences.

Definitions of Hypertension, Awareness, Treatment, and Control of Hypertension  Hypertension was defined according to two definitions: 1) DBP \(\geq 90\) mm Hg or SBP \(\geq 140\) mm Hg or use of antihypertensive drugs; 2) DBP \(\geq 95\) mm Hg or SBP \(\geq 160\) mm Hg or use of antihypertensive drugs. Awareness was defined as mentioning that an elevated blood pressure had been assessed in the past. Subjects were classified as pharmacologically treated for hypertension when the question ‘Are you taking medication to lower blood pressure?’ was answered in the affirmative and at least one antihypertensive drug was mentioned. Control of hypertension among those treated was defined according to two definitions: 1) DBP < 90 mm Hg and SBP < 140 mm Hg; 2) DBP < 95 mm Hg and SBP < 160 mm Hg.

RESULTS

Repeated measurements of blood pressure were available from a sample of 924 subjects from the population of the screening project conducted from 1987 to 1992. After exclusion of subjects treated with antihypertensive drugs or diet for hypertension (n = 75) and pregnant women (n = 15), blood pressure measurements from 834 subjects were used in the analysis of variance to estimate the within-person variances. The within-person variances of diastolic and systolic blood pressure and the corresponding \(s_b/s_{\text{obs}}\) ratios are listed in Table 1. The estimates of within-person variance and the correction factors varied slightly with age and gender. Within-person variability and the corresponding correction factors were higher for systolic blood pressure than for diastolic blood pressure.

After correction for WPV, the prevalence of hypertension decreased, whereas the prevalences of awareness of hypertension and treatment of hypertension increased (Table 2). The prevalence of control of hy-
Hypertension among treated hypertensives increased only slightly. For hypertension 1 and 2 these changes were of the same magnitude for prevalence of hypertension (38% and 39%, respectively), awareness (214% and 212%, respectively), treatment (228% and 228%, respectively), and control of hypertension (23% and 25%, respectively). With increasing age the overestimation of the prevalence of hypertension decreased, whereas the underestimation of the prevalence of awareness and treatment of hypertension decreased. The underestimation of the prevalence of control of blood pressure among treated hypertensives showed no clear trend with age.

The overestimation of the prevalence of hypertension was higher for men than for women, whereas the underestimation of the prevalence of awareness of hypertension was somewhat higher for men than for women. The underestimation of the prevalence of treatment of hypertension was similar for men and women for hypertension definition 1, whereas for definition 2 this underestimation was higher for men than for women. No differential change in the prevalence of control of hypertension by gender was observed for either hypertension definition.

**DISCUSSION**

In this study we demonstrated that the prevalence of hypertension without a correction of blood pressure values for WPV was substantially overestimated, whereas the prevalence of awareness and treatment of hypertension were substantially underestimated. The prevalence of control of hypertension did not change much after this correction. These changes in prevalence estimates were similar for two widely used definitions of hypertension. The observed trends of the over- and underestimations with age and gender can

| TABLE 1. ESTIMATES OF WITHIN-PERSON VARIANCE OF BLOOD PRESSURE AND CORRECTION FACTORS (RATIO OF $s_b/s_{obs}$) |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| **Diastolic Blood Pressure**     | **Systolic Blood Pressure**     | **[Table 1.](#)***              |
| Age (Years)                     | Number                          | $s^2_{wb}$*                     | $s^2_{ww}$†                     | $s_b/s_{obs}$ (95% CI)‡        |
|                                |                                 |                                 |                                 |                                 |
| **Men**                         |                                 |                                 |                                 |
| 20–29                           | 328                             | 30.04                           | 15.30                           | 0.66 (0.60–0.72)               |
| 30–39                           | 432                             | 26.18                           | 10.16                           | 0.81 (0.78–0.84)               |
| 40–49                           | 444                             | 35.79                           | 11.21                           | 0.73 (0.68–0.77)               |
| 50–59                           | 464                             | 30.48                           | 13.09                           | 0.81 (0.78–0.84)               |
| **Women**                       |                                 |                                 |                                 |
| 20–29                           | 348                             | 24.05                           | 11.83                           | 0.82 (0.78–0.85)               |
| 30–39                           | 392                             | 27.45                           | 10.63                           | 0.74 (0.70–0.79)               |
| 40–49                           | 488                             | 25.07                           | 11.24                           | 0.73 (0.69–0.77)               |
| 50–59                           | 442                             | 30.05                           | 11.52                           | 0.79 (0.75–0.82)               |
| *Within-person variance of blood pressure between visits.*  
| †Within-person variance of blood pressure within a visit.*  
| ‡Correction factor $s_b/s_{obs}$.  
| CI, confidence interval. |

*Percentage of hypertensives.*  
†Percentage of hypertensives.  
‡Percentage of treated hypertensives.
be explained by the proportion of treated hypertensives. Correction for WPV has no effect on treatment status. Therefore, when the proportion of treated hypertensives is higher, the influence of correction for WPV on prevalence, awareness, and treatment of hypertension is less. The relatively small influence of the correction for WPV on the prevalence of control of hypertension can be explained by the relatively small difference between the average blood pressure in the group of treated hypertensives and the cut-off point to define control of hypertension.

Overestimation of the within-person variance would lead to overcorrection of prevalence estimates. It is possible to control for these effects that are correlated with time, as shown by Shepard.8 In our internal reproducibility study, a time interval between visits of 1 year was used. Subjects who were dieting, pharmacologically treated hypertensives, and pregnant women were excluded from our sample to prevent systematic changes in blood pressure from contributing to the estimate of within-person variance. In a study by Rosner and Polk,9 between-visit components of within-person variance of DBP and SBP of 26.2 mm2 Hg and 50.2 mm2 Hg were estimated. The time interval between visits was at most 1 week in this study, which suggests that our estimates of within-person-between-visit variance were probably not overestimated due to a too-long time interval between visits.

Hypertensive patients who have been treated pharmacologically on the basis of too few measurements of blood pressure could have caused an overestimation of the prevalence of hypertension, but this is difficult to evaluate.

Our findings have major implications for the evaluation of prevalence estimates, awareness, and treatment of hypertension when these are based on only a few measurements of blood pressure. Interpretation of these estimates without taking into account within-person variability of blood pressure measurements could lead to wrong conclusions about the level, awareness, and treatment of hypertension in the population. Currently, newer methods for the measurement of blood pressure, such as ambulatory monitoring and home blood pressure measurements using recording devices, are available.11,12 Potentially, these methods could more easily provide a precise assessment of a person’s average blood pressure, as well as more valid prevalence estimates. However, when this is not feasible it may be advisable to perform a correction for within-person variability to obtain valid prevalence estimates in surveys that take one or two measurements of blood pressure.

REFERENCES