Reference Values for Self-recorded Blood Pressure

A Meta-analysis of Summary Data

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Background: The widespread clinical use of self-recorded blood pressure measurement is limited by the lack of generally accepted reference values. The purpose of this study was therefore to perform a meta-analysis of summary data in an attempt to determine an operational threshold for self-recorded blood pressures.

Studies and Methods: Seventeen studies, including a total of 5422 subjects, were reviewed. Eight of these 17 studies included both normotensive and untreated hypertensive subjects, while the other 9 reports included normotensive subjects only. Within each study an operational cutoff point between normotension and hypertension was derived by means of the mean+2 SDs and the 95th percentiles of the self-recorded blood pressure in normotensive subjects. These 2 methods were contrasted with 2 other techniques that have been applied in the literature to calculate (1) the self-recorded pressures equivalent to a conventional pressure of 140 mm Hg systolic and 90 mm Hg diastolic by means of regression analysis and (2) the self-recorded blood pressures at the percentiles corresponding to a conventional pressure of 140/90 mm Hg. The latter 2 methods were applied in untreated subjects not selected on the basis of their blood pressure.

Results: With weighting for the number of subjects included in the various studies, the self-recorded blood pressure averaged 115/71 mm Hg in normotensive persons and 119/74 mm Hg in untreated subjects not selected on the basis of their blood pressure. The reference values for self-recorded blood pressures determined by the mean+2 SDs (137/89 mm Hg) or the 95th percentile (135/86 mm Hg) of the distribution in normotensive subjects were concordant within 2/3 mm Hg, whereas the cutoff points derived with the regression and percentile methods were considerably lower, ie, 125/79 and 129/84 mm Hg, respectively.

Conclusions: Until the relationship between self-recorded pressure and the incidence of cardiovascular morbidity and mortality is further clarified by prospective studies, a mean self-recorded blood pressure above 135 mm Hg systolic or 85 mm Hg diastolic may be considered hypertensive.

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METHODS

SOURCES OF INFORMATION

Articles published in English, French, or German between January 1960 and March 1996 were searched for data on self-recorded blood pressure. The papers were retrieved by a computerized bibliographic search, using MEDLINE. The following key words in title or abstract were looked for: “self-recorded blood pressure” or “home blood pressure.” Because an electronic search may miss a significant proportion of published studies,28 the computer search was supplemented by some manual searching via references of published articles, via the table of contents of journals published in 1996, and by questioning experts in the field.

Published studies including normotensive subjects and subjects not selected on the basis of their blood pressure were considered for inclusion in the meta-analysis. Studies comparing the self-recorded blood pressures in normotensive and hypertensive persons were also considered, but only the normotensive subgroups were included in the meta-analysis. Articles on hypertensive subjects only and studies of special subgroups (pregnant women, diabetic patients, patients with heart failure, hemodialysis patients, etc) were excluded. Also excluded were studies of subjects whose blood pressure was measured at home by a relative. A total of 18 articles that met the inclusion criteria were identified.12,20-45 There was no indication that the same subjects were included in more than 1 report.

DATA COLLECTION

Information retrieved from the studies included year of publication, number of participants in each study, the participants’ sex and age distribution, the device used for self-measurement, and the number of self-recorded pressures obtained in each subject. In addition, several variables describing the distribution of the self-recorded blood pressures were obtained (see the “Statistical Methods” section). Authors were contacted for missing data and for summary statistics that could not be calculated from the published results. Of the 18 investigators contacted, 6 provided the requested data.30,32,34,39,44 6 replied that the data were no longer available.33,36-38,40,41 1 did not consider a meta-analysis the appropriate approach to the research question,42 and the remaining 5 did not reply.12,20,35,43,45

STATISTICAL METHODS

Database management and statistical analyses were performed with SAS software (SAS Institute Inc, Cary, NC).

Within each study, an operational threshold between normotension and hypertension for the self-recorded blood pressures was calculated by means of the mean+2 and the 95th percentile34 of the self-recorded blood pressures in subjects who were considered normotensive according to conventional sphygmonanometry. In the literature, 2 other approaches to calculating an upper limit of normal self-recorded blood pressure have been used, ie, the regression and the percentile methods. The former consists of calculating the regression line between the self-recorded and conventional blood pressure values of individual patients and determining the self-recorded blood pressure that would correspond to a conventional blood pressure of 140 mm Hg systolic or 90 mm Hg diastolic.42 The regression method, as applied by Mancia et al,42 only considers the point estimate and does not take into account the SD on the prediction of an individual value (Figure 1, left). The percentile method involves calculating the percentile of the clinical blood pressure that would correspond to 140 mm Hg systolic or 90 mm Hg diastolic and determining the self-recorded blood pressure that would correspond with the same percentile value32,45 (Figure 1, right). The latter 2 approaches have been applied in subjects not selected on the basis of their blood pressure. However, persons receiving drug treatment for hypertension were excluded. Although the approach based on the mean+2 SDs or its nonparametric equivalent in normotensive subjects is to be preferred (see the “Comment” section), the regression and percentile methods were also reviewed to provide a complete summary of the literature and to compare the various methods.

Means computed for all studies combined were weighted for the number of subjects included in each separate study.

RESULTS

DESCRIPTION OF THE STUDIES

Of the 18 identified studies, 1 was excluded because only data on mean blood pressure were presented and additional data could not be obtained.35 The main characteristics of the remaining 17 studies are given in Table 1. The number of subjects in each of the individual studies ranged from 1412 to 1438.42 Eight reports did not apply any selection criteria based on blood pressure values.32,34,36,38,40,42,43,45 Mean age ranged from 16 years30 to 47 years.45 Six studies included only men.30,35,37,39,41,44 One study recruited exclusively young (≤25 years) black men.35 Sixty percent of the volunteers included in the study by Kesteloot et al 40 were Korean.

The subjects measured their blood pressure by an automatic or semiautomatic oscillometric device in 5 studies,31,32,34,42,45 by a semiautomatic auscultatory device in 4,29,39,43,44 and by a manual sphygmonanometer in 7 reports.12,30,35,37,36,40,41 In most studies the subjects measured their blood pressure during several days (range, 1-63 days), usually in the morning and in the evening. The number of self-recorded blood pressures averaged for analyses ranged from 242 to 252.36
AVERAGE SELF-RECORDED BLOOD PRESSURE IN NORMOTENSIVE SUBJECTS

Average self-recorded systolic and diastolic blood pressures in the normotensive subjects included in the various studies, either reported or obtained from the authors, were available from a total of 14 studies and are plotted together with the corresponding 95% confidence intervals in Figure 2.

The self-recorded blood pressure, in the 14 studies combined, averaged 115/71 mm Hg. In addition, the 95% confidence limits of the mean reported in Figure 2 indicate...
In 4 studies, results were reported for men and women. The average self-recorded blood pressure in the 8 studies combined averaged 119/74 mm Hg. The 5 studies that reported on the association between self-recorded blood pressure and age uniformly showed that the self-recorded systolic and diastolic blood pressures increased with advancing age. However, because the reported summary statistics differed from study to study, no overall age effect could be calculated. Regression analysis indicated that the self-recorded blood pressure increased by 3.8/3.0 mm Hg per decade in the study by Kesteloot et al and by 3.3/4.4 mm Hg per decade in the study by de Gaudemaris et al. Imai et al reported an increase in self-recorded blood pressure from 112/67 mm Hg in subjects aged 20 to 39 years to 127/74 mm Hg in those older than 60 years. In the study by Weisser et al, the self-recorded blood pressure in the same subgroups averaged 117/73 mm Hg and 132/82 mm Hg, respectively. Mancia et al also reported an increase in the self-recorded blood pressure with age. Precise values were, however, not available in the published report.

**AN OPERATIONAL THRESHOLD FOR SELF-RECORDED BLOOD PRESSURE**

The numbers of normotensive persons included in the various studies are given in Table 1. Figure 4 and Table 2 show the means±2 SDs and the 95th percentiles of the self-recorded blood pressures in these normotensive subjects. The means of these boundaries for all studies combined, weighted for the number of subjects in each study, are presented in Table 3. The means±2 SDs in the various studies, taken as a possible cutoff point, averaged 137 mm Hg systolic and 89 mm Hg diastolic. The regression and percentile methods were reviewed, considering only the studies that did not preselect their participants on the basis of their blood pressure.
For all of these studies combined, regression analysis indicated that a conventional systolic blood pressure of 140 mm Hg was equivalent to a self-recorded pressure of 125 mm Hg, while a conventional diastolic pressure of 90 mm Hg corresponded to 79 mm Hg (Table 3). These figures are weighted means of point estimates; no confidence limits were presented in the published reports. The weighted means of the thresholds derived by means of the percentile method amounted to 129 mm Hg systolic and 84 mm Hg diastolic.

The widespread clinical use of self-recorded blood pressure measurements, a promising technique for the diagnosis and management of hypertension, is limited by the lack of generally accepted reference values. Establishing an operational threshold for self-recorded blood pressures requires that the relationship between these measurements and the incidence of cardiovascular complications be clarified further by prospective studies. Moreover, the benefits of using self-monitoring as an accessory to conventional sphygmonanometry must be established in prospective clinical trials. The Treatment of Hypertension According to Home or Office Blood Pressure (THOP) trial is currently investigating whether antihypertensive treatment guided by self-measured blood pressure would be more beneficial than treatment based on conventional sphygmonanometry. While the results of these trials are awaited, the present study pooled the available data from 17 published cross-sectional studies in an attempt to determine a reference frame for self-recorded blood pressure by means of several approaches.

**COMMENT**

The widespread clinical use of self-recorded blood pressure measurements, a promising technique for the diagnosis and management of hypertension, is limited by the lack of generally accepted reference values. Establishing an operational threshold for self-recorded blood pressures requires that the relationship between these measurements and the incidence of cardiovascular complications be clarified further by prospective studies. Moreover, the benefits of using self-monitoring as an accessory to conventional sphygmonanometry must be established in prospective clinical trials. The Treatment of Hypertension According to Home or Office Blood Pressure (THOP) trial is currently investigating whether antihypertensive treatment guided by self-measured blood pressure would be more beneficial than treatment based on conventional sphygmonanometry. While the results of these trials are awaited, the present study pooled the available data from 17 published cross-sectional studies in an attempt to determine a reference frame for self-recorded blood pressure by means of several approaches.

**DETERMINING THE UPPER LIMIT OF THE DISTRIBUTION IN NORMOTENSIVE SUBJECTS**

The present study determined an operational threshold between normotension and hypertension for the self-recorded blood pressure by calculating the mean±2 SDs and the 95th percentile of the distribution in subjects who were normotensive only.
diagnosed as being normotensive on conventional sphygmomanometry. The approach based on the mean+2 SDs is a parametric method that assumes normally distributed data. In contrast, the approach based on the 95th percentile limit is a nonparametric and distribution-free method. Its application is therefore not limited by the characteristics of the underlying distribution. Both the parametric and nonparametric methods attempt to determine the upper end of the distribution of the self-recorded blood pressure in normotensive people who are known to have a lower cardiovascular risk than patients who are hypertensive on conventional sphygmomanometry.

In the present meta-analysis, the reference values for the self-recorded blood pressure determined by the parametric and nonparametric approaches were concordant within 2/3 mm Hg. They amounted to 135 and 137 mm Hg systolic and 86 and 89 mm Hg diastolic, respectively. These thresholds are in close agreement with those proposed by Tsuji et al47 based on a prospective study of 1913 Japanese subjects recruited from a rural Japanese community. The relative risk of mortality in hypertensive vs normotensive subjects was greater if the diagnosis was based on the self-recorded (137/84 mm Hg) rather than on the conventional (140/90 mm Hg) blood pressure.

DETERMINING THE SELF-RECORDED BLOOD PRESSURE CORRESPONDING TO A CONVENTIONAL BLOOD PRESSURE OF 140/90 mm Hg

The aforementioned methods to calculate an operational threshold between normotension and hypertension for self-recorded blood pressures were contrasted with 2 other techniques that have been used in the literature. The first of these 2 techniques is a parametric method that calculates by linear regression the self-recorded pressure corresponding to a casual blood pressure of 140 mm Hg systolic and 90 mm Hg diastolic42,49 (Figure 1, left). The second nonparametric method determines the self-recorded blood pressure that has the same percentile ranking as a conventional blood pressure of 140/90 mm Hg22,45 (Figure 1, right). Both methods have been applied in subjects who did not take antihypertensive drugs but were not preselected on the basis of their blood pressures.

The reference values derived with the latter 2 methods were considerably lower than those based on the upper end of the distribution of the self-recorded blood pressure in normotensive people, ie, 125/79 mm Hg and 129/84 mm Hg for the regression and percentile approaches, respectively. The discordance may be explained by various mechanisms. First, plots relating the self-recorded to the office blood pressure values usually show a wide scattering of points around the regression line.24 As a consequence, with the regression method, a large part of the subjects who are considered normotensive on the basis of their casual blood pressure readings are labeled hypertensive on the basis of their self-recorded blood pressures. For example, in the Japanese study by Imai et al,26 26% of the “casual normotensive subjects” had a self-recorded blood pressure above the upper limit of normal derived by regression analysis. From these observations it is clear that, when the regression method is applied, not only the point estimate but also the SD of the prediction of an individual value should be taken into account49 (see Figure 1, right). Boundaries corresponding to the upper 95% prediction limit around the regression line were, however, not reported in the published articles. Second, regression analysis assumes that the independent variable, ie, the conventional blood pressure, is fixed.30 However, in reality, conventional blood pressure readings are subject to random variation, because of measurement error and temporary deviations of the blood pressure from the usual level. This results in an underestimation of the slope of the real association between the self-recorded and conventional blood pressures, a phenomenon called regression dilution bias.51 Third, in view of the white-coat effect, the slope of the regression line relating the self-recorded to the conventional blood pressure could well be different in normotensive and hypertensive subjects. This hypothesis should be tested and, if confirmed, would invalidate the regression method. Fourth, the percentile method requires that the same percentage of subjects be classified as hypertensive whether diagnosed by conventional or self-recorded blood pressures. However, one would expect fewer hypertensive patients with self-measurement because 1 of the main advantages of the latter approach is the exclusion of subjects with white-coat hypertension.2 This condition may be present in 7% to 73% of the patients with an elevated office blood pressure.

VARIABILITY BETWEEN AND WITHIN STUDIES

The studies included in the present meta-analysis were quite heterogeneous. First, subjects were recruited in different ways. Some studies recruited a random sample of the population12,38,42,54; others reported data from volunteers,12,33 students,32,39,40 or workers.32,38 Heterogeneity between studies could be a limited factor, but also allows one to study the impact of the characteristics of the individual studies on the overall results. For example, the study by Mengden et al43 included employees who attended a blood pressure screening program. Fifty percent of these employees had a conventional pressure above 140/90 mm Hg. This probably explains the relatively high value of 125/84 mm Hg for the mean self-recorded blood pressure in this study as compared with the overall mean self-recorded pressure of 119/74 mm Hg (Figure 3). Second, there were many methodological differences between the studies included in this meta-analysis. Indeed, different blood pressure monitoring devices were used, the number of self-recorded blood pressures averaged for analysis differed widely, and the position of the subjects was not always the same. The time of day at which the self-recorded blood pressures were taken also differed slightly between studies. Several studies showed that self-recorded blood pressures are lower in the morning than in the evening.20,22,28,60-67 Therefore, it has been advised that blood pressure always be measured at the same time of the day.18,20,28 In most of the studies included in the present meta-analysis, blood pressure was measured during several days both in the morn-
ing and in the evening. The average of all values was used for analysis.

Not only between but also within individual studies there were large differences between subjects. Most studies recruited both men and women of different ages and races and from different social classes. Only a few studies in unselected subjects reported on the effect of sex and age on the self-recorded blood pressure. In these studies, the self-recorded blood pressure tended to be higher in men than in women and increased with age. The preliminary thresholds for the self-recorded blood pressure proposed in this report do not take into consideration sex and age. However, the boundaries currently in use for the conventional pressure and jointly endorsed by several expert committees, eg, 140/90 mm Hg and 160/95 mm Hg, are also uniformly applicable to men and women and across all ages. Because summary statistics on the distribution of the self-recorded blood pressure in men and women separately and in separate age classes were available from only a few studies, it was not possible to study in detail the effect of these covariates on the self-recorded blood pressure. However, according to the method followed for ambulatory blood pressure monitoring, an international database on individual self-recorded blood pressures is currently being constituted in an attempt to apply the same statistical approach and quality standards across studies. This database will also allow detailed study of the inference of several covariates on the self-recorded blood pressure and will provide the means to contrast the distributions of the self-recorded blood pressure measurements from subjects who are either normotensive or hypertensive according to conventional sphygmomanometry.

CONCLUSION

Until the relationship between self-recorded pressure and cardiovascular morbidity and mortality is further clarified by prospective studies, a self-recorded blood pressure above 135 mm Hg systolic or 85 mm Hg diastolic could be considered hypertensive. These values are similar to the thresholds proposed for the daytime ambulatory blood pressure. 

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REFERENCES


