Arterial Blood Pressure
Correlation With Erythrocyte Count, Hematocrit, and Hemoglobin Concentration

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The relationship between arterial blood pressure and red blood cell variables was investigated in 1013 unselected persons with a blood pressure range of 90 to 225 mm Hg systolic and 50 to 145 mm Hg diastolic. Statistically significant correlations were demonstrated between mean (as well as systolic and diastolic) arterial blood pressure and red blood cell count ($r = 0.27$; $P < .0001$), hematocrit ($r = 0.28$; $P < .0001$), and hemoglobin concentration ($r = 0.29$; $P < .0001$). Average arterial blood pressure was higher in men than in women ($133 \pm 16/83 \pm 10$ *v* $124 \pm 16/79 \pm 9$ mm Hg, $P < .0001$) and this was associated with higher values for erythrocyte count, hemoglobin concentration, and hematocrit in men as compared to women. The significant correlation of blood pressure and hematocrit, which represents one important determinant of blood viscosity, points to a role for rheological factors in the long-term control of blood pressure. Moreover, it might be speculated that the sex difference in blood pressure as observed in the present study may be due, at least in part, to stimulated erythropoiesis in men as compared to women. Am J Hypertens 1991;4:14–19

KEY WORDS: **Arterial blood pressure, erythrocyte count, hematocrit, hemoglobin concentration.**

It is generally agreed that in the majority of patients arterial hypertension is associated with increased total peripheral resistance.[11] In addition to the geometry and size of the resistance vessels, peripheral vascular resistance is also influenced by the rheologic parameter blood viscosity[3,24] which, among other things, is determined by the red blood cell variable hematocrit (Hct).[25] Although occasional reports have described the occurence of coronary heart disease and peripheral vascular disease in conditions with high blood viscosity,[5,9,18] this parameter has so far attracted little attention as a factor with possible importance in the regulation of arterial blood pressure.

Over the past ten years, an impressive number of studies have been published on abnormalities of red cell membrane cation transport in hypertension.[15] It remains unclear, however, whether these claimed changes in erythrocytes of hypertensive patients may be associated with alterations in clinical erythrocyte parameters such as red blood cell count, mean corpuscular volume (MCV), or mean hemoglobin concentration (MCHC). Changes in MCV, for instance, should be expected if carriers are involved that are capable of producing a net solute transport across the cell membrane, such as the sodium pump or the Na-K cotransport system.[6,27]

These two lines of thinking prompted us to investigate whether arterial blood pressure can be correlated with red blood cell variables.

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TABLE 1. CHARACTERISTICS OF THE PARTICIPANTS

	Total	Men	Women	*P* Value
n	1013	523	490	
Age (yrs)	27.2 ± 5.8	27.8 ± 5.0	26.6 ± 6.5	<.001
Body mass index (kg/m^2)	21.8 ± 2.8	22.7 ± 2.6	20.9 ± 2.6	<.0001
Systolic BP (mm Hg)	128.3 ± 16.3	132.7 ± 15.8	123.5 ± 15.6	<.0001
Diastolic BP (mm Hg)	81.2 ± 10.1	83.4 ± 10.2	78.9 ± 9.4	<.0001
Mean BP (mm Hg)	96.9 ± 10.9	99.8 ± 10.6	93.8 ± 10.3	<.0001
HR (min^{-1})	71.8 ± 12.8	70.2 ± 12.8	73.5 ± 12.6	<.0001
ALT (U/l)	12.5 ± 6.3	14.5 ± 7.3	10.4 ± 4.2	<.0001
Creatinine (μmol/L)	76.7 ± 10.6	82.4 ± 8.6	70.5 ± 8.9	<.0001
RBC (10^6 μL^{-1})	4.78 ± 0.41	5.06 ± 0.31	4.50 ± 0.30	<.0001
Hb (g/dL)	14.7 ± 1.2	15.6 ± 0.9	13.8 ± 0.8	<.0001
Hct (%)	42.7 ± 3.3	44.8 ± 2.4	40.4 ± 2.4	<.0001
MCV (f1)	89.2 ± 3.9	88.6 ± 3.6	89.8 ± 4.2	<.0001
MCH (pg)	30.8 ± 1.4	30.9 ± 1.2	30.7 ± 1.5	NS
MCHC (g/dL)	34.5 ± 1.0	34.8 ± 0.9	34.1 ± 1.1	<.0001

Characteristics of the participants in the study are given as total values and for men and women separately. P *values indicate significance levels of the differences between men and women.*

BP = blood pressure; HR = heart rate; ALT = alanine aminotransferase; RBC = red blood cell count; Hb = hemoglobin concentration; Hct = hematocrit; MCV = mean corpuscular volume; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration; NS = not significant.

SUBJECTS AND METHODS

One thousand and thirteen participants (490 women and 523 men) were enrolled in the study. The subjects were unselected public employees receiving no medication with the exception of oral contraceptives (n = 175, 35.7% of the female participants). They attended our outpatient facilities for routine clinical examination. People with obvious anemia (hemoglobin concentration (Hb) < 10 g/dL) were excluded from the study. Likewise, people with a calculated alcohol intake of more than approximately 50 g/day were not included in the study.

Arterial blood pressure and heart rate were measured once, using phase V of Korotkoff's sound for diastolic blood pressure (or twice, if blood pressure was found to be elevated) after a quiet sitting period of 15 min. Mean blood pressure was calculated from diastolic pressure plus one-third of the pulse pressure. Body mass index (BMI) was computed using the weight/height squared relation.

Blood samples were obtained from the antecubital vein between 9:00 AM and noon. Hematologic parameters were determined using a Coulter counter (Model S5; Coulter Electronics, Krefeld, West Germany). In previous experiments, a high correlation between hematocrit derived from microhematocrit measurements and from the coulter counter method[13] was demonstrated (r = 0.95; n = 52).

Data are given as means ± SD. Statistical analysis of data was performed using the SAS statistical package (SAS Institute Inc., Cary, North Carolina). Correlations were calculated using the formula for the Pearson's correlation coefficient and further analyzed by a stepwise regression procedure. Mean values between men and women were compared by unpaired Student's *t* test. Differences were considered to be significant when a *P* value of less than .05 was reached.

TABLE 2. CORRELATION OF BLOOD PRESSURE WITH VARIOUS VARIABLES

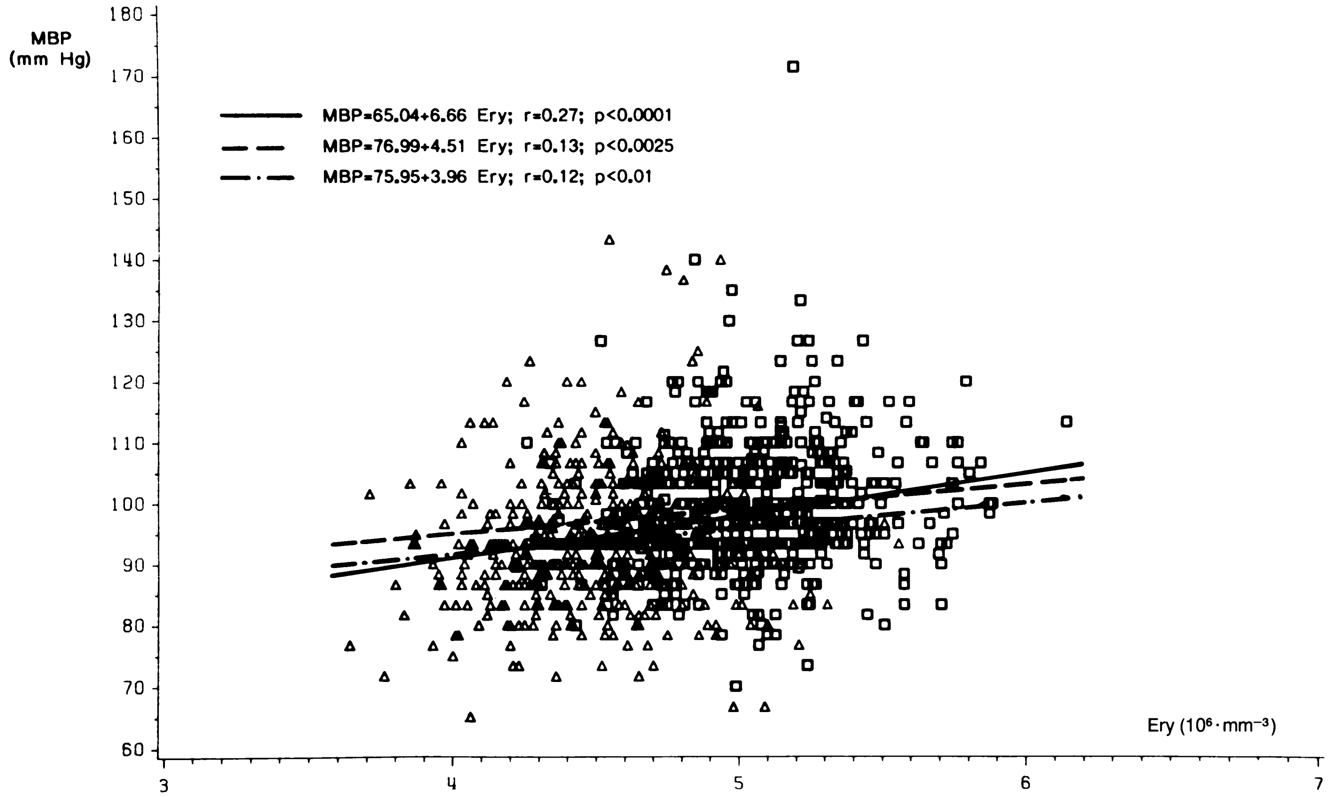
	r	*P* Value
Body mass index (kg/m^2)	0.34	.0001
Hb (g/dL)	0.29	.0001
HR (min^{-1})	0.15	.0001
Age (yrs)	0.19	.0001
Creatinine (μmol/L)	0.20	.0001
ALT (U/L)	0.24	.0001

Correlation analysis of various parameters with mean arterial blood pressure. Given are the Pearson's correlation coefficients and the significance levels.

See Table 1 for abbreviations.

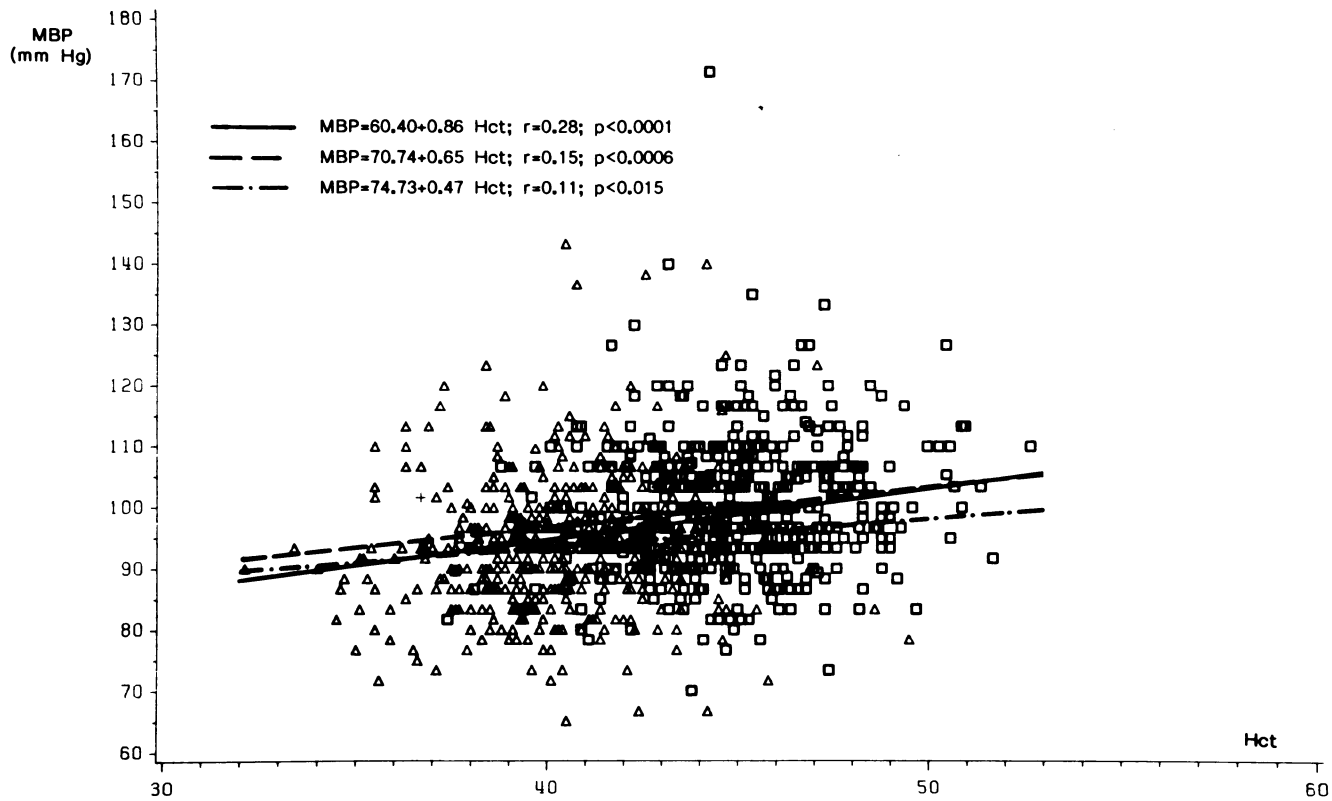
RESULTS

The characteristics of the participants are summarized in Table 1. Male subjects had higher systolic, diastolic, and mean arterial blood pressure values than female subjects. The opposite was true for heart rate, with women exhibiting higher values. Age and body mass index were also slightly higher in men. Likewise, creatinine concentrations and the activity of alanine aminotransferase



MBP (mm Hg)
MBP=65.04+6.66 Ery; r=0.27; p<0.0001
MBP=76.99+4.51 Ery; r=0.13; p<0.0025
MBP=75.95+3.96 Ery; r=0.12; p<0.01
Ery (10⁶·mm⁻³)

A



MBP (mm Hg)
MBP=60.40+0.86 Hct; r=0.28; p<0.0001
MBP=70.74+0.65 Hct; r=0.15; p<0.0006
MBP=74.73+0.47 Hct; r=0.11; p<0.015
Hct

B

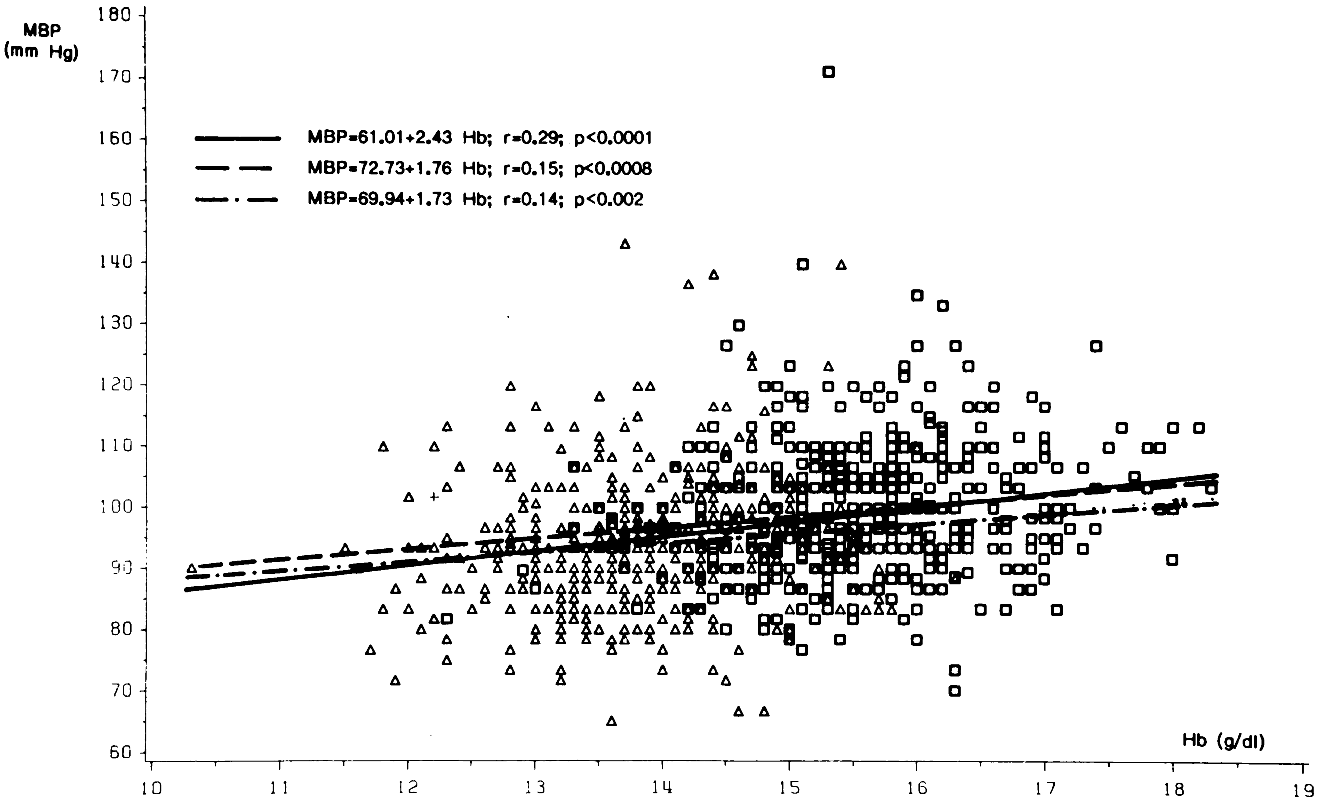


FIGURE 1. *Correlations of mean blood pressor with (A) red blood cell count (Ery), (B) hematocrit (Hct), and (C) hemoglobin concentration (Hb). Illustrated are the single values for females (△) and males (□) and the regression lines for the group as a whole (—), and separately for females (– – –) and males (— —).*

(ALT) showed higher values in men. With regard to red blood cell variables, men had significantly higher erythrocyte counts, hemoglobin concentrations (Hb), hematocrit values (Hct), and mean corpuscular hemoglobin concentrations (MCHC). Mean corpuscular volume (MCV) was slightly, albeit significantly, higher in women, whereas no difference could be detected in mean corpuscular hemoglobin (MCH).

Systolic, diastolic, and mean arterial blood pressure was significantly correlated with age, heart rate, body mass index, serum creatinine and serum ALT activity (Table 2). Stepwise regression analysis reveals that hemoglobin concentration ranks second following body mass index with respect to correlation with mean blood pressure.

Among the red cell variables investigated, no correlation could be demonstrated between blood pressure and mean corpuscular volume (MCV) or mean hemoglobin concentration (MCHC). However, a significant positive correlation could be demonstrated between systolic, diastolic, and mean arterial pressure on the one hand and the interrelated variables erythrocyte count, hemoglobin concentration in whole blood and hematocrit, as depicted in Figure 1 for mean arterial blood pressure, on the other. Significance values and correlation coefficients were in the same order for systolic and diastolic pressure, respectively. It should be noted, however, that these correlations were markedly weaker when women and men were analyzed separately (Figure 1).

DISCUSSION

The results of this study show that among unselected and untreated people, a positive correlation between hematocrit (and the related variables hemoglobin and erythrocyte count) and arterial blood pressure can be established. Earlier studies have reported higher hematocrit values in rats with genetic hypertension[26] and in hypertensive patients, as compared to normotensive controls.[4,8,12,19,20,28] Although the present study is in agreement with those earlier observations, it should be emphasized that we describe a positive correlation between arterial blood pressure and these erythrocyte parameters over a wide pressure range. Taken together, these findings may point to hemorheologic factors as determinants of arterial blood pressure because blood viscosity varies directly with hematocrit, a relationship described by Einstein in 1905.[25]

If a positive correlation between arterial blood pressure and red blood cell count and/or hematocrit indeed exists, the question arises whether this is due to changes in the absolute number of erythrocytes. Alternatively, the observed correlation could represent a relative increase in hematocrit due to extracellular and consequently blood volume contraction. Alterations in plasma volume with resulting hemoconcentration cannot be ruled out in our study because plasma volume was not measured. To date, conflicting results have been presented with respect to plasma volume in hypertensive patients and in animals with genetic and experimental hypertension.[2,7,11,14,29,30] In the aforementioned study by Sen et al,[26] the increase in red blood cell mass observed in hypertensive as compared to control rats could not be associated with changes in plasma volume. It therefore appears that changes in plasma volume may not substantially contribute to the correlations between red blood cell variables and blood pressure, as observed in the present study.

Sen et al speculated that an increased erythropoietin production in spontaneously hypertensive rats could be linked not only to erythrocytosis but also to elevated blood pressure.[26] In this respect, it is noteworthy that hypertension is a common side effect of treatment with recombinant erythropoietin in patients with anemia in endstage renal failure.[10,17,23] However, red cell transfusions in anemic patients with chronic renal failure increase total peripheral resistance and thereby increase diastolic blood pressure in direct proportion to the increase in hematocrit values.[22] This may be regarded as another indication that hemorrheologic factors such as viscosity are important factors in blood pressure control. Whether erythropoietin possesses pressor activity independent of its action on red blood cell formation remains unclear.

It is especially noteworthy that data from residents in high altitude, such as the Indians in the Andes, are at variance with our findings. These people have lower systolic and diastolic blood pressures despite a substantially higher red cell mass, than people living at the coast.[16] Obviously, the hypoxic environment evokes reactions of the circulatory control systems that counterbalance the effect of high hematocrit and, thus, high blood viscosity.

Blood pressure and some erythrocyte parameters were higher in men than in women (Table 1) and positive (although weaker) correlations between these variables could be established within both sex groups (Figure 1). Androgens are known to account for the consistent differences in red cell mass between men and women; they have been shown to stimulate erythropoietin production by a direct action on the kidney.[1,21] It is important to note that the differences in red blood cell mass between men and women parallel those in arterial blood pressure. Whether the observed sex differences in red blood cell variables are causally linked to the blood pressure differences remains unclear.

Another interesting finding in the present study is the lack of correlation between blood pressure and the variables MCV and MCHC, which may be taken as indicators for erythrocyte volume. Thus, if abnormalities in red blood cell membrane transport systems are associated with elevations in blood pressure, they are unlikely to produce long-term changes readily detectable as alterations in red blood cell volume.

In conclusion, the present study demonstrates that, over a wide range of arterial blood pressure, a positive correlation can be observed between red blood cell count, hematocrit and hemoglobin concentration. This study therefore supports the concept that hemorheologic factors may participate in the regulation of arterial blood pressure. However, for a definite analysis further studies incorporating measurements of hematocrit, viscosity, blood pressure, blood volume and peripheral resistance are needed.

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