Right- and Left-arm Blood Pressure Discrepancies in Vascular Surgery Patients

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To identify a relationship between atherosclerotic vascular disease and differences in blood pressure between the right and left arms, blood pressure differences between arms were measured in patients with peripheral vascular disease (PVD, n = 58), in patients with coronary artery disease (CAD, n = 38), and in patients with no evidence of atherosclerotic disease, who served as a control group (n = 38). The incidence and magnitude of right and left arm pressure difference determined by the oscilometric technique were compared between the patient groups. The incidence of systolic pressure difference ≥ 20 mmHg between arms in patients with PVD (21%) was greater than that in either those with CAD (5%) (P < 0.05) or control subjects (0%) (P < 0.05). The incidence of systolic pressure difference ≥ 45 mmHg between arms in patients with PVD (10%) was greater than that in either those with CAD (0%) (P < 0.05) or control subjects (0%) (P < 0.05). Patients with PVD also had a greater incidence of right and left arm difference than did those with CAD or controls for mean and diastolic blood pressures. Of all patients with a systolic difference greater than 10 mmHg, neither the right nor the left arm blood pressure was consistently higher: 21 of 35 (60%) had a higher pressure in the right arm, and 14 of 35 (40%) had a higher pressure in the left arm (P = 0.33). Gender, diabetes, hypertension, smoking, and age were not associated with a difference in blood pressure between the right and left arms. The PVD group was divided according to clinical presentation of atherosclerotic lesions. These subgroups were then compared regarding blood pressure difference between arms. Patients with carotid disease and combined carotid/CAD had the highest mean systolic pressure differences (18 and 26 mmHg respectively), both of which were significantly higher than in controls (5 mmHg) (P < 0.001). The findings indicate that patients with PVD have a high incidence and magnitude of right- and left-arm blood pressure discrepancies compared to patients with coronary disease alone or those with atherosclerotic disease. The authors suggest the measurement of blood pressure in both arms in patients with PVD when diagnostic and therapeutic decisions are made. (Key words: Anesthesia; cardiac, vascular. Blood pressure; measurement; right and left differences.)

The arterial blood pressure is used to monitor the integrity of the cardiovascular system and is one of the most common physiologic parameters upon which clinical decisions are based. For measurement of blood pressure, the American Heart Association recommends, “On the initial examination it is usually best to record the pressure in both arms. In subsequent examinations the arm found to have the higher pressure initially should be used.”

Despite this recommendation, many physicians and other health care professionals measure the blood pressure in only one arm, favoring the arm that is most accessible at the time of the examination. This error in clinical practice could lead to the mismanagement of patients with blood pressure disorders when a significant right- and left-arm blood pressure difference goes unrecognized.

Although modern medical texts often ignore the issue, blood pressure has long been known to vary from one arm to the other. Several investigators have shown that the general population has a high incidence of blood pressure differences. Hypertension, but not age, sex, or handedness, has been associated with blood pressure differences. It has also been recognized that the blood pressure in the right arm tends to be higher than that in the left arm in those patients with a pressure difference between arms.

The first association of right- and left-arm blood pressure difference with vascular disease was made by Osler, who in 1915 stated, “While the arterial blood pressure in aneurysm is either normal or slightly above, in a majority of cases of thoracic aneurysm there is a marked difference in the blood pressure in the two arms and when this is greater than 20 mmHg it is a point in favor of aneurysm.” In the past, before the introduction of modern diagnostic procedures such as angiography and computerized tomography scanning, physicians used these right- and left-arm blood pressure differences as a crude diagnostic test to predict diseases of the great vessels. However, no reports in the literature have investigated whether patients with known atherosclerotic vascular disease have a higher incidence of difference in blood pressure between arms when compared to those patients without vascular disease.

The study described here compared the incidence and magnitude of right- and left-arm blood pressure difference in patients with peripheral vascular disease and those with coronary artery disease to patients without atherosclerotic vascular disease. The purpose is to identify a subset of patients with a high incidence of right and left arm differences.
Materials and Methods

Patient Assignment

With approval from our Institutional Review Board, 134 hospitalized patients were prospectively studied. These patients were selected over a 4-month period from different wards within the hospital specific for vascular, cardiac, urologic, and orthopedic surgery. The medical history, physical examination, and medical records were reviewed to assign the patients to one of three groups: patients with no evidence of atherosclerotic disease (control, n = 58), and those with evidence of coronary artery disease (CAD, n = 58), or peripheral vascular disease (PVD, n = 58). Patients in the control group were hospitalized for reasons other than vascular disease and had no evidence of CAD or PVD by history or physical examination. Patients in the CAD group had one or more of the following: a documented myocardial infarction, angina pectoris, prior coronary artery bypass surgery, angioplasty, or angiographic documentation of coronary artery lesions. Patients in the PVD group had either angiographic evidence or a history of vascular intervention (surgical or angioplasty) of the carotid, aortic, iliac, femoral, or popliteal arteries. The CAD group included only patients without evidence of PVD. Patients with clinical evidence of both CAD and PVD were initially included in the PVD group and later analyzed separately as patients with combined disease.

For further comparison, the PVD group was divided into smaller groups according to the specific site or sites of vascular disease (Table 1). Angiographic documentation, prior carotid artery surgery, transient ischemic attack, or cerebral vascular accident was evidence for carotid disease (n = 6). Angiographic documentation or prior vascular intervention (surgical or angioplasty) was evidence for femoral–popliteal (n = 15) or aortoiliac (n = 18) disease. Patients with combined PVD and CAD were analyzed in a separate category as having combined aortoiliac/CAD (n = 8), femoral–popliteal/CAD (n = 6), and carotid/CAD (n = 5). The patients with diffuse atherosclerotic disease involving three or more of the above sites were analyzed as a group, designated as patients with three or more vascular diseases (n = 5).

In addition to the vascular disease groups, other factors designated as the covariates (hypertension, diabetes, smoking, sex, and age) were evaluated to identify any association with right- and left-arm blood pressure differences. Hypertension was defined as a previous physician diagnosis of high blood pressure or current or past treatment with antihypertensive medications. Diabetes was defined as physician diagnosis or current or past treatment with insulin or oral hypoglycemic agents. Smoking was defined as having smoked cigarettes, cigars, or a pipe at any time, regardless of current smoking habits. Patients who were not able to give a reliable medical history were not included in the study.

Blood Pressure Measurement

The blood pressures were measured using the automated oscillometric technique, (Dinamap 1846 SX/P, Critikon, Tampa, FL), in awake patients resting comfortably in the supine position. All blood pressures in any given patient were taken with the same machine, and most of the patients were studied using the same machine. All Dinamap machines had been recently calibrated electronically with a digital pressure meter. First the investigator visited with the patient to obtain consent and describe the study. Then the appropriate cuff was chosen so that the width of the cuff was at least 20% greater than the diameter of the arm, as recommended by the American Heart Association. The right arm blood pressure was determined using the mean of three measurements taken consecutively, with less than 30 s between readings. Immediately afterward, the left arm blood pressure was determined by the same process. Systolic, mean, and diastolic blood pressures were recorded, and the mean blood pressure also was calculated using the standard formula (diastolic blood pressure + [systolic blood pressure – diastolic blood pressure]/3). The final analysis was done using the calculated mean blood pressures.

The absolute difference between the right- and left-arm blood pressures was used to compare the patients from the different groups. The incidence of absolute right- and left-arm blood pressure difference at various levels of magnitude was compared in the control, CAD, and PVD groups. For systolic blood pressure the data were analyzed for differences of ≥ 10, ≥ 15, ≥ 20, and ≥ 45 mmHg between arms. For mean blood pressure the data were analyzed for differences of ≥ 10, ≥ 15, and ≥ 20 mmHg. For diastolic blood pressure the data were analyzed for differences of ≥ 5, ≥ 10, and ≥ 15 mmHg.

<table>
<thead>
<tr>
<th>Table 1. Patient Population</th>
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<td>Patients (number)</td>
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<tr>
<td>Control</td>
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<tr>
<td>CAD</td>
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<tr>
<td>PVD</td>
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<tr>
<td>Aortoiliac</td>
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<td>Femoral–popliteal</td>
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<td>Aortoiliac/CAD</td>
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<tr>
<td>Femoral–popliteal/CAD</td>
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<tr>
<td>Carotid/CAD</td>
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<td>More than three vascular diseases</td>
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CAD = coronary artery disease; PVD = peripheral vascular disease.
The mean absolute blood pressure differences then were compared for the specific subgroups of PVD and CAD versus the control group.

**Statistical Analysis**

The groups were compared with regard to age using one-way analysis of variance (ANOVA). The population differences for sex, diabetes, hypertension, and smoking and the incidence of absolute right- and left-arm blood pressure difference at various levels of magnitude were analyzed with chi-squared analysis and Fisher's exact tests. The mean absolute right- and left-arm differences then were compared among control, CAD, and the various vascular disease groups using a stepwise regression with adjustment for all covariables (age, sex, smoking, diabetes, and hypertension) that were statistically significant at the $P \leq 0.12$ level. Of these covariables, only age was shown to be significant at this level. All values given are mean ± standard error of the mean. For all statistical comparisons, $P \leq 0.05$ was considered significant.

**Results**

Differences between the control, CAD, and PVD groups with regard to sex, age, and the incidence of diabetes, hypertension, and smoking are shown in Table 2. The PVD patients had a significantly greater incidence of diabetes, hypertension, and smoking compared to controls. Diabetes was more common in CAD patients than in controls. The patients in the PVD group were slightly older than those in the CAD group. There was not a statistically significant relationship between right- and left-arm blood pressure difference and sex, age, smoking, hypertension, or diabetes.

The incidence of absolute systolic right- and left-arm blood pressure difference in the PVD group was greater than that in both the control and CAD groups. This difference was statistically significant for differences of $\geq 10$, $\geq 15$, $\geq 20$, and $\geq 45$ mmHg (Table 3). The incidence of absolute mean right- and left-arm blood pressure difference in the PVD group was greater than that in the control and CAD groups. This difference was statistically significant for differences of $\geq 10$ mmHg and $\geq 15$ mmHg for PVD versus control, and $\geq 10$ mmHg for PVD versus CAD (Table 4). The incidence of absolute diastolic right- and left-arm blood pressure difference in the PVD group was greater than that in the control and CAD groups. This difference was statistically significant for differences of $\geq 10$ mmHg for PVD versus control and for differences of $\geq 5$ and $\geq 10$ mmHg for PVD versus CAD (Table 5). Of particular note is the relatively high incidence of systolic differences in the PVD group compared to both CAD and control groups. Twenty-one percent of patients in the PVD group had systolic differences of $\geq 20$ and 10%
TABLE 5. Diastolic Blood Pressure Differences (Absolute) Between the Right and Left Arm

<table>
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<tr>
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<th>Pressure Difference (mmHg)</th>
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<td></td>
<td>≥5</td>
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<tr>
<td>Control (n = 58)</td>
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<tr>
<td>CAD (n = 58)</td>
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<td>PVD (n = 58)</td>
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Values are number of patients with stated blood pressure difference; percentages are given in parentheses.

CAD = coronary artery disease; PVD = peripheral vascular disease.

* P ≤ 0.01 versus control.
† P ≤ 0.05 versus CAD.
‡ P ≤ 0.01 versus CAD.

had differences of ≥ 45 mmHg, whereas not one patient in the CAD or control groups had a difference of ≥ 45 mmHg, and only one patient in the CAD group had a difference of ≥ 20 mmHg (table 3).

There were no significant differences in the incidence of right- and left-arm blood pressure difference between the control and CAD groups for systolic, mean, or diastolic blood pressures (tables 3–5). Both the control and CAD groups had a low incidence of blood pressure difference.

Patients with different types of vascular diseases were compared to control patients with regard to the mean absolute blood pressure difference between the right and left arms for systolic, mean, and diastolic blood pressures. For systolic differences the aortoiliac, femoral-popliteal, carotid, and carotid/CAD groups and the group with more than three vascular diseases all differed significantly from control (fig. 1). For mean differences the aortoiliac, carotid, and carotid/CAD groups and the group with more than three vascular diseases all differed significantly from control (fig. 2). For diastolic differences the carotid, aortoiliac/CAD, and carotid/CAD groups and the group with more than three vascular diseases all differed significantly from control (fig. 3). Patients in the CAD group did not differ from controls with regard to mean absolute right and left arm blood pressure differences for systolic, mean or diastolic blood pressures (figs. 1–3).

In patients with a right- and left-arm difference of ≥ 10 mmHg, regardless of patient group, the higher blood pressure was not consistently found in either the right or left arm. Of these patients, 21 of 35 (60%) had a higher pressure in the right arm, and 14 of 35 (40%) had a higher pressure in the left arm. The tendency for the right arm to exceed the left arm blood pressure was not statistically significant.

**Discussion**

The data presented here show that patients with PVD have a relatively high incidence and magnitude of right- and left-arm blood pressure difference, compared to patients with CAD alone or patients without vascular disease. The value of identifying a subset of patients with a high incidence of right- and left-arm pressure difference is clear. It is probable that when there is a difference, the higher blood pressure more accurately reflects central aortic pressure, and therefore the arm with the higher

**FIG. 1.** Systolic blood pressure differences (absolute) between the right and left arm in patients categorized by disease groups. *P ≤ 0.05 versus control; ***P ≤ 0.001 versus control.

**FIG. 2.** Mean blood pressure differences (absolute) between the right and left arm in patients categorized by disease groups. **P ≤ 0.01 versus control; ***P ≤ 0.001 versus control.

**FIG. 3.** Diastolic blood pressure differences (absolute) between the right and left arm in patients categorized by disease groups. *P ≤ 0.05 versus control; ***P ≤ 0.01 versus control.
pressure should be used when making clinical decisions. Moll et al. demonstrated that 85% of patients with a significant difference in right- and left-arm systolic blood pressure had angiographic evidence of innominate or subclavian artery stenosis on the side with the lower blood pressure. Their study, then, also suggests that the arm with the higher pressure more accurately represents the "true" blood pressure.

By identifying a subset of patients with a high incidence of right- and left-arm blood pressure difference, the awareness of this problem and the recognition of these patients can be increased, and the mismanagement of blood pressure disorders in these patients may be avoidable. One type of mismanagement in the case of a significant right- and left-arm blood pressure difference is the phenomenon of "pseudohypotension." A patient may be falsely diagnosed as hypotensive if the blood pressure is taken only in the arm with the lower reading. The patient may have a normal or high blood pressure in the other arm and may be inappropriately treated with vasoconstricting or inotropic drugs. Many patients with PVD have concomitant CAD and therefore may not tolerate the increase in myocardial oxygen demand associated with these drugs.

Another potential clinical error is the overlooking of or the inadequate treatment of acute or chronic hypertension. This occurs when a hypertensive patient with a significant right- and left-arm blood pressure difference is evaluated with a blood pressure that is taken only in the arm with the lower reading. This problem could arise in the acute setting in the hospital or in the physician's office during a routine visit. If the same arm is used routinely for measuring the blood pressure in every patient, the likelihood of not identifying hypertension is increased. Untreated or inadequately treated chronic hypertension may put patients at risk for complications such as cerebral vascular accidents, renal failure, congestive heart failure, and CAD. In view of recent studies of the reduction of morbidity and mortality by treatment of even mild hypertension (diastolic blood pressure 94 mmHg), it seems prudent to monitor blood pressure accurately in these patients; this implies the necessity of bilateral measurements, especially in those with PVD.

There is yet another subset of patients in which bilateral measurement of blood pressure is extremely important. Patients scheduled for coronary artery bypass graft surgery may develop the lethal complication of coronary-subclavian steal syndrome if the internal mammary artery is used to supply coronary flow in a patient with subclavian stenosis. In this syndrome the internal mammary artery graft develops reverse flow either at rest or during exercise of the ipsilateral upper extremity, leading to myocardial ischemia or death. By using careful bilateral blood pressure measurements as a preoperative screening test, subclavian stenosis should be detected and perhaps further evaluated with angiography during cardiac catheterization. The surgical plan could then be modified to use an aortocoronary saphenous vein graft and thereby avoid the subclavian steal syndrome. The findings of our study suggest that patients with a history of PVD who undergo coronary artery bypass surgery should have the blood pressure checked in both arms before surgery.

The mechanism causing blood pressure discrepancies has not been investigated. Atherosclerotic disease is a systemic disorder that is often diffuse in its distribution, and it is possible that the lesions involve the subclavian and/or axillary arteries, creating a stenotic area that lowers blood pressure in the extremity. Our demonstration of the high incidence and magnitude of right- and left-arm blood pressure difference in patients with carotid disease supports this hypothesis. Since the carotid and subclavian arteries are branches of the innominate on the right and branches of the aorta on the left, there may be some anatomic correlation between atheromatous disease in the carotid, subclavian, and the innominate arteries. That the subclavian arteries supply blood flow to the upper extremities may explain the high incidence of right- and left-arm differences in patients with carotid disease. It could be that CAD has different characteristics than PVD: CAD patients may have a more localized form of atherosclerosis with less subclavian involvement, which would explain the lower incidence of differences in blood pressure between the two arms. Indeed, atherosclerotic disease may affect the coronary arteries earlier and more severely than the cerebral arteries. Other evidence for the difference between CAD and PVD is that coronary arteries have a significantly higher content of total lipids, with a higher percentage of triglycerides, cholesterol, and mineral matter when compared to the systemic vessels.

The degree of right- and left-arm blood pressure difference that should be considered clinically relevant depends on the clinical setting. Some primary care physicians might diagnose as hypertensive any patient with a diastolic blood pressure even slightly greater than 90 mmHg, whereas the diagnosis of hypotension in the perioperative period would be more subjective, depending on the clinician's practice and the patient's baseline blood pressure. We analyzed the data at several levels of blood pressure

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difference between arms (5, 10, 15, 20, and 45 mmHg) to allow clinicians to make their own interpretations. Certainly, there should be little disagreement that the maximum right- and left-arm difference in the patients studied here (64 mmHg for systolic blood pressure) is clinically significant.

Use of the oscillometric device for blood pressure determination may be justified on several counts. One of the difficulties encountered when performing blood pressure studies is the elimination of observer bias. Most of the earlier investigations2-11 measured blood pressure using the Korotkoff method, which has been shown to produce unreliable measurements depending on the technique of the clinician.23 Because these studies2-7,9-11 made no effort to mask the observer, the potential for erroneous results was increased. Also, the accuracy and working condition of both aneroid and mercury sphygmomanometers have been shown to be less than adequate.22,23 By using an automated device, observer bias can be removed and accurate readings obtained. Blood pressures taken using the automated oscillometric system used in the current study have been shown to correlate well with measurements by direct arterial cannulation.24 How the accuracy of this machine varies with atherosclerotic vascular changes is not known.

Patient assignment in this study was based on clinical history, physical examination, and review of the medical records. Patients did not receive angiographic evaluation to assess the distribution of atherosclerosis as part of this study, although many patients did have angiograms if they were hospitalized primarily for manifestations of PVD or CAD. Therefore, the results are applicable to patients with clinical evidence of these diseases.

Because we did not measure a central pressure, we did not test the hypothesis that the arm with the higher blood pressure more accurately reflects the pressure in the central aorta. It is possible that bilateral stenotic lesions are present in the vascular tree and that neither the right nor the left arm blood pressure reflects the true aortic blood pressure. In this case it would be difficult if not impossible to recognize the problem and to obtain a true blood pressure without direct aortic cannulation, which, to our knowledge, has not been attempted.

Since in routine evaluation few patients receive three blood pressure measurements by the oscillometric technique in each arm, the question arises as to how the findings of this study relate to clinical practice. The data presented here leave two questions unanswered. First, how reliable for comparison is a single measurement taken in each arm? Second, are measurements taken with the Korotkoff technique sufficiently accurate to diagnose right- and left-arm differences? Although the study did not specifically address these issues, it is likely that a sufficiently large difference between right- and left-arm blood pressure will be recognized with a single, carefully taken measurement using either the oscillometric or the Riva–Rocci technique. If these questions are to be answered definitively, further investigation is necessary.

In summary, patients with PVD have a high incidence of right- and left-arm blood pressure difference when compared to patients without vascular disease or with CAD alone. Also, the right or left arm does not consistently predominate as the arm with the higher blood pressure when there is a difference between arms. Clinicians should be aware of this potentially misleading phenomenon and should monitor the blood pressure using bilateral measurements, especially in patients with known PVD. Although this hypothesis has not been investigated, the authors propose that the arm with the higher blood pressure more accurately represents the "true" blood pressure, and suggest using this arm for taking measurements and making clinical decisions.

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References

2. Shock NW, Ogden E: The differences between blood-pressure measurements obtained simultaneously on the two arms. Q J Exp Physiol 30:155–162, 1940