venography. Termination of the IPG sequence even after two 45-second occlusion time tests would have decreased this specificity by 14%. Furthermore, if the common practice was followed of terminating the IPG series after one normal result with 45 seconds of occlusion, a 10% deterioration in sensitivity would have occurred. These observations emphasize the practical importance of achieving optimal venous filling and also provide a physiological basis for standardizing impedance plethysmography.

References

Arterial Insufficiency of the Hand Evaluated by Digital Blood Pressure and Arteriographic Findings

MASAFUMI HIRAI, M.D.

SUMMARY In 80 hands with arterial occlusive disease, systolic blood pressure at the wrist and in all fingers was measured by photoelectric plethysmography. The correlation of such pressures with angiographic evidence of organic obstruction or the development of digital ischemic signs was studied. Digital blood pressure was normal in all 184 fingers in which there was at least one obstruction-free arterial path to and through the finger. Ischemic signs developed in only one. Of 203 fingers with occlusion in vessels in or leading to both sides of the finger, a decreased pressure was seen in 173 and a normal pressure in 30. Ischemic signs were observed in 132 of 173 fingers with a decreased pressure, and in two of 30 with a normal pressure. The clinical significance of measurement of digital blood pressure in arterial occlusive disease is discussed.

IN THE EVALUATION of arterial insufficiency of the hand, the five fingers should be studied separately, since the degree of ischemia is often different in each finger. Especially in the early stage of the disease, only one or two fingers may be involved. Arteriography may be used for this type of study. However, arterial occlusion in arteriograms does not always indicate digital ischemia. During recent years there has been an increasing interest in measuring the blood pressure of the limbs, because blood pressure values correlate with the function of the collaterals and the clinical findings.1–8 By using strain gauge or photoelectric plethysmography with a blood pressure cuff, blood pressure measurement can be carried out in all fingers.6,7 However, there has not yet been a detailed study regarding clinical significance of blood pressure measurement in all fingers. Downs et al.8 reported the correlation of digital blood pressure with arteriographic findings in hands with arterial occlusion, but they did not deal with the development of digital ischemia.

In the present study, systolic blood pressure at the
wrist and in all five fingers was measured by a photo-electric technique in patients with arterial occlusive diseases of the hand. The correlation of such pressures with angiographic evidence of organic arterial obstruction or the development of digital ischemic signs was investigated, and the clinical value of blood pressure measurement in all fingers was discussed.

Materials and Methods

From August 1976–March 1978, brachial arteriography was performed on 94 limbs of 53 patients with arterial occlusive diseases of the limbs. It was carried out on 41 limbs of 28 patients for ischemic symptoms of the hand, for cold sensitivity in 30, for rest pain in one and for gangrene in 10 limbs. Arteriograms showed occlusive lesions in all 41 limbs. In the remaining 53, arteriography was performed regardless of the absence of clinical evidence of upper limb blood flow disturbance to define the frequency and pathophysiology of upper extremity involvement in Buerger’s disease. Thirty-nine of the 53 limbs had arterial occlusions. In the present study, 80 arms of 50 patients in which arterial occlusive lesions of the hand were seen in arteriograms were selected.

All patients were men, ranging in age from 28–67 years (mean 46 years). All had normal brachial pulses and no bruits over the subclavian arteries were audible. In all patients, ischemia of the leg was observed through the absence of one or more pulsations of the leg, with a significant decrease in toe systolic pressure.4–6 Forty-three cases were diagnosed as Buerger’s disease and seven as arteriosclerosis obliterans, according to clinical and arteriographic findings.9, 10 Most cases were primarily diagnosed because of ischemia in the feet.

Of 28 patients with ischemic signs of the hand, three were admitted to the hospital with complaints of symptoms of upper limb blood flow disturbance alone, despite the fact that the ischemia of the leg was observed by physical examinations as described above. The remaining 25 patients complained of ischemic symptoms of the upper limb associated with lower limb symptoms. The chronological relationship between the onset of the disease in the lower limb and upper limb is summarized in Table 1.

In 16 of 41 hands with ischemic signs, development of ischemia was observed in all fingers, and the remaining 25 hands included at least one symptom-free finger (Table 2). The most serious clinical problems in 135 fingers which suffered from ischemia were cold sensitivity in 115, rest pain in two and gangrene in 18.

Brachial arteriography was undertaken under general anesthesia to eliminate the possibility of secondary arterial spasm. With local anesthesia, the patient may experience sharp pain and is more likely to move during exposure of the films. Retrograde puncture of the brachial artery was performed in the antecubital fossa and 15 ml of contrast medium (60% Conray) was injected rapidly by hand or with an automatic injector. Twenty films were exposed over at least 15 seconds. The usual rate was 1 film/sec. No serious complications occurred.

In all hands studied, systolic blood pressure was measured at the wrist and in all fingers by photoelectric plethysmography.11 Systolic blood pressure was determined by slowly deflating the cuff pressure from suprasystolic values and recording the first inflow with a photocell placed on the fingertip. At the wrist, a 12 cm wide cuff was used. In measurement of digital blood pressure, a 24 mm wide cuff was applied to the proximal phalanx in the first finger and a 20 mm wide cuff to the intermediate phalanx in the lateral four fingers. The above procedure was carried out three times at each level and the mean was used for evaluation. With all measurements, the arm systolic pressure was measured by the standard auscultatory method, using a 12 cm wide cuff, and the difference in blood pressures between the wrist or the finger and the arm was used in the analysis of results. In the lateral four

### Table 1. Chronological Relationship between the Onset of Ischemic Signs in the Lower and Upper Limbs

<table>
<thead>
<tr>
<th>Development of Upper Limb Symptoms</th>
<th>Prior to lower limb symptoms</th>
<th>Within one year after</th>
<th>1-3 years after</th>
<th>3-5 years after</th>
<th>5-10 years after</th>
<th>More than 10 years after</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases</td>
<td>4</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 2. Arterial Occlusion Site and a Number of Fingers with Ischemic Signs in 80 Hands

<table>
<thead>
<tr>
<th>Occlusion site</th>
<th>No. of cases</th>
<th>None</th>
<th>1 finger</th>
<th>2 fingers</th>
<th>3 fingers</th>
<th>4 fingers</th>
<th>5 fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both of radial and ulnar a.</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Radial a.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ulnar a.</td>
<td>29</td>
<td>18</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Hand a.*</td>
<td>9</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital a.</td>
<td>21</td>
<td>17</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Hand arteries included deep or superficial palmar arch, common digital artery, metacarpal artery and princeps pollicis artery.
fingers, digital blood pressure was also measured at the proximal phalanx, using a 24 mm wide cuff in fingers II, III and IV and a 20 mm wide cuff in finger V to compare the diagnostic value for digital ischemia between blood pressure values recorded at the intermediate phalanx and at the proximal phalanx.

Blood pressure measurements were also carried out in 80 normal subjects, and the lower limits of normal values were determined for the two groups divided according to age, to be used in the evaluation of patients with arterial occlusive diseases. They consisted of 43 males and 37 females. Their ages ranged from 17-87 years (mean 46 years). These normal subjects were members of the staff of the hospital and volunteers. None of the subjects showed any clinical evidence of peripheral arterial disease or ischemic symptoms.

### Results

Arterial occlusion sites in arteriograms and a number of fingers with ischemic signs are summarized in table 2. In 58 of 59 hands with occlusion of the radial, ulnar or hand arteries, occlusion of the proper digital arteries was also observed, in addition to proximal occlusive lesions. Development of ischemic signs in all fingers was observed in 15 hands with occlusion of both radial and ulnar arteries and in one with occlusion of the ulnar artery.

The pressure gradients between the wrist and the arm and between each finger and the arm in normal persons are shown in table 3. The lower limits of normal values of these pressure gradients were determined by the mean minus 2.5 standard deviations. As there was no significant difference in blood pressures between the fingers, one normal value of finger-arm pressure gradient was calculated.

In six arms, a significantly decreased blood pressure was observed at the wrist. In these limbs, arteriograms revealed occlusion of both radial or ulnar arteries proximal to the wrist. Even if one of the radial or ulnar arteries was occluded proximal to the wrist, a normal blood pressure was observed.

In order to correlate arteriographic findings with systolic blood pressure in each finger, the arteriograms were examined in detail for evidence of arterial obstruction at any site. In particular, an attempt was made to trace the main individual pathways from arteries in the forearm or hand, and along each of the digital arteries. Depending on the arteriographic findings, 387 of 400 fingers from 80 hands were classified into three groups: normal flow finger group (NG), uninterrupted flow finger group (UG) and interrupted flow finger group (IG). In the remaining 13 fingers, no correlation was attempted, because there were doubts about the interpretation of the angiograms for vessels supplying the fingers. The NG group consisted of 99 fingers. In this group, no organic abnormalities were seen in vessels supplying the fingers. In the UG group, consisting of 85 fingers, only one digital artery was supplied by its own metacarpal or common digital arteries through the more proximal arteries without interruption. The IG group consisted of 203 fingers. Occlusion was seen in both digital arteries or more proximal arteries supplying the finger, indicating that the blood supply to the finger depended on the collateral circulation.

Digital blood pressure was recorded as normal in all 184 fingers classified into the NG or UG groups. Ischemic signs were observed in only one finger. Of 203 fingers classified into the IG, 173 showed an abnormally low digital blood pressure, and the remaining 30 fingers showed a normal blood pressure. Ischemic signs developed in 132 of 173 fingers with a decreased digital pressure and in two of 30 fingers with a normal digital pressure (fig. 1).

In arteriograms, the development of collateral
vessels was seen at the site of occlusive lesions. In the finger, anastomotic arcuate vessels were often observed. In the palm area, it was usually found that the residual palmar arch, as well as metacarpal and common digital arteries, was involved in the formation of collateral vessels. Although 30 fingers in which digital blood pressure was normal (despite the fact that they belonged to the IG group) were expected to have well-developed collateral vessels, it was sometimes difficult to determine accurately the degree of development of collateral vessels on the basis of angiographic findings (figs. 2-4).

In 109 fingers with digital ischemic signs, a comparison was made between blood pressure values recorded at the intermediate phalanx and those at the proximal phalanx. A decreased digital pressure was observed in 107 fingers (98%) at the intermediate phalanx, and 93 (85%) at the proximal phalanx (fig. 4).

### Discussion

In the present study, all 184 fingers in which there was at least one obstruction-free arterial path to and through the finger showed a normal digital pressure. Of 203 fingers with occlusion in vessels in or leading to both sides of the finger, a decreased digital pressure was observed in 173 and a normal pressure in 30. Downs et al. also reported a correlation between the arteriographic evidence of organic obstruction and digital blood pressure. In their results, of 68 fingers in which a normal digital pressure was expected, 55 had a normal pressure, leaving 13 with false positive indication of obstruction. Of 67 fingers in which a decreased pressure was expected because of occlusion in vessels in or leading to both sides of the finger, 63 showed a low pressure and four a normal pressure. The fact that the incidence of false positive pressures was lower and that of false negative pressures was

<table>
<thead>
<tr>
<th>Arteriographic Findings</th>
<th>Digital Blood Pressure</th>
<th>Ischemic Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Flow Finger Group (n=99)</td>
<td>Normal (n=99)</td>
<td>Yes (n=1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No (n=98)</td>
</tr>
<tr>
<td>Uninterrupted Flow Finger Group (n=85)</td>
<td>Normal (n=85)</td>
<td>No (n=85)</td>
</tr>
<tr>
<td>Interrupted Flow Finger Group (n=203)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal (n=30)</td>
<td>Yes (n=2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No (n=28)</td>
</tr>
<tr>
<td></td>
<td>Low (n=173)</td>
<td>Yes (n=132)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No (n=41)</td>
</tr>
</tbody>
</table>

**Figure 1.** Correlation of digital blood pressure with arteriographic findings and development of ischemic signs in 387 fingers.

**Figure 2.** Case I. A 33-year-old man with Buerger's disease. Arteriogram shows occlusion of the ulnar artery and lateral digital arteries of fingers II, III, IV and V. The medial digital artery of finger III is supplied from well-developed collateral vessels connected with the princeps pollicis artery, resulting in normal digital pressure. Although the medial digital artery of fingers IV and V are visualized through the poor collateral vessels, blood pressure is normal in finger IV, but low in finger V. The first finger was classified into the normal flow finger group, finger II into the uninterrupted flow finger group and the others into the interrupted flow finger group.
higher in our results may be explained by the difference in criteria used for interpretation of the arteriograms. When the digital arteries were supplied with blood from arteries which were in other routes than usual, even if the size of these arteries seemed to be sufficient for normal blood transmission, these fingers were classified into the IG group in our study, as shown in finger III of case 1 (fig. 2). It is difficult to judge with certainty whether these unusual arteries should be regarded as normal pathways or collaterals, because many variations of the hand arteries have been reported.24, 25 Furthermore, 39 of 80 hands investigated in our study showed no ischemic signs, even though arterial occlusion was shown in the arteriograms. The study including these asymptomatic hands may result in a high incidence of false negative pressures.

Although well-developed collateral circulations were expected in 30 fingers with false negative pressures, it was sometimes difficult to determine accurately the degree of development of collateral vessels on the basis of arteriographic findings (figs. 2–4). However, as only two of these 30 fingers showed development of ischemic signs, determination of blood pressure might be considered helpful as a functional diagnostic measure to estimate objectively the flow volume of collateral vessels in arterial occlusive disease.

In the correlation between digital blood pressure and development of digital ischemic signs in each finger, no ischemic signs were observed in 211 of 214 fingers with a normal digital blood pressure. From this
result, it might be considered that if digital blood pressure is normal, ischemic signs rarely develop in arterial occlusive disease, even though arterial occlusion is seen in arteriograms.

The other three fingers with ischemic signs should be noted. One of them occurred in a 46-year-old man engaged in ceramic art. At the age of 29, he first noticed ischemic gangrene on the toes, and Buerger’s disease was diagnosed. Thereafter, gangrene occurred in the toes on both sides, resulting in spontaneous loss of all toes. At the age of 46, he entered the hospital with a four-month history of cyanosis of the fingertips of fingers I, II and III, which developed after working for six months at his job of driving a potter’s wheel using these fingers. Brachial arteriography revealed occlusion of the ulnar artery and of both digital arteries of the lateral four fingers. In the first finger, both digital arteries were visualized well through the radial artery without interruption. Blood pressure measurement revealed a decreased blood pressure in the lateral four fingers and a normal blood pressure in finger I. Therefore, it was considered that damage to microcirculation of the fingertip due to the repeated dull stimulus to the fingers might have contributed to the development of the ischemic symptom.

In the remaining two fingers, occlusion of the digital arteries on the arteriograms occurred distally to the cuff. Presumably, if the cuff were moved distally on the fingers, a decreased digital pressure would be obtained.

Of 173 fingers with a decreased digital pressure, ischemic signs of the fingers developed in 132. This finding may indicate that the individual variations in sensitivity to cold, the environment of life or work and the degree of disturbance in digital microcirculation due to local trauma or to microemboli also influence the development of ischemic symptoms in addition to impaired digital circulation due to arterial occlusion in or leading to the finger. Arteriography gives valuable information regarding the site and extent of obstruction of the arterial tree and is employed preoperatively where the surgeon has need of a “road map.” Furthermore, it may be used for determination of the underlying etiology. For example, regular and smooth lumens of the arteries proximal to the occlusion site is a common finding in Buerger’s disease, and is one of the criteria for distinguishing it from arteriosclerosis obliterans. However, arteriography can be quite time-consuming, and involves some risk to the patient. In contrast, blood pressure measurement is easily and rapidly performed. All measurements in both arms can be made in approximately 1 hour. In the present study, it was shown that digital arterial ischemia secondary to arterial occlusive disease could be established with a high degree of accuracy by pressures alone. Therefore, the use of arteriography merely to confirm the diagnosis of arterial insufficiency may be unnecessary.

In the clinical use of digital blood pressure, the measurement should be carried out at the intermediate phalanx in the lateral four fingers, since this method has higher diagnostic value, as shown in the present study. Furthermore, digital blood pressure should be measured in all fingers, as development of ischemic signs in all fingers was observed in only 16 of 80 hands. Determination of blood pressure in one or two fingers only may miss confirmation of arterial insufficiency of the hand.

In addition to the diagnostic value, digital blood pressure measurement might be valuable in assessing follow-up in patients with arterial occlusive disease, because measurement can be easily repeated and given a quantitative diagnosis. Patients with a decreased digital pressure, even though they show no ischemic symptoms, should be advised to avoid exposure of the hand to cold.

Blood pressure measurement is not always useful in patients with spastic diseases such as Raynaud’s disease. Our previous study showed that such cases might have a normal digital pressure even if ischemic signs are observed. Our conclusion of the previous study was that a patient with cold sensitivity of the hand and a normal digital pressure should not be considered to have an arterial occlusive disease as the underlying etiology for cold sensitivity. Furthermore, a normal blood pressure does not always indicate the absence of occlusive disease. Blood pressure measurement is effective in the evaluation of the functional abnormality.

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Stability of Blood Pressure Rank and Urinary Kallikrein Concentration in Childhood: An Eight-Year Follow-Up

Stephen H. Zinner, M.D., Harry S. Margolius, M.D., Ph.D., Bernard Rosner, Ph.D., and Edward H. Kass, M.D., Ph.D.

Summary

Previous studies in a population of 721 children aged 2 to 14 years demonstrated the familial aggregation of blood pressure in children, and a significant regression coefficient (b = 0.25) of follow-up on initial blood pressures over a four-year period. Urinary kallikrein concentration (UKal) also aggregated in families, was lower in black than in white children and was inversely related to blood pressure.

Further studies in the same cohort have been conducted. These variables were again measured in 484 children in 129 families seven to eight years after the initial blood pressure and three to four years after the original UKal measurements were made.

Familial aggregation again was found for blood pressure and urinary kallikrein. Blood pressure tracking was demonstrated by the finding that blood pressure scores at the third survey were related significantly to those at both previous surveys.

Kallikrein concentrations in casual urines at Survey 3 were related to those obtained at Survey 2 ($r = 0.499$), and were again significantly lower in black than in white children ($\log = 3.84 \pm 0.8$ vs $4.37 \pm 0.7$; $P < 0.001$). There were significant inverse relations between UKal/creatinine concentration and blood pressure in both white and black children.

Thus, familial aggregation of blood pressure, blood pressure rank and concentration of kallikrein in casual urine specimens are relatively stable in children over an eight-year period of observation. This study demonstrates in a free living population of normal children, a stable relation between blood pressure and an enzyme which is involved in the production of potent vasodilator peptides and is related to hypertension in adults.

Studies in Adults have suggested that blood pressures are not only familialy aggregated, but that blood pressures obtained in early adulthood are predictive of pressures attained later in life; that is, that relative blood pressure rank tends to be stable in successive surveys. In order to determine if these characteristics of adult blood pressures were also present in childhood, a study of blood pressures was begun in 1967 in families of children aged 2 to 14 years. This study reported that blood pressures were familialy aggregated in children with correlation coefficients similar to those found in adults. These findings were confirmed in several other populations. A second survey of the original cohort of children four years later showed that familial aggregation of blood pressure persisted and that there was a significant positive relation between the blood pressures obtained in the initial and follow-up surveys.

Possible biochemical correlates of the blood pressure status of the children were sought. Several systems and biochemicals are related to the maintenance of systemic arterial pressure, including the renin-angiotensin-aldosterone axis, the central and sympathetic nervous systems and, perhaps, prostaglandins and kinins. Because measurement of the activity of these systems often requires blood samples and expensive methodology, we searched for a urine component that might be useful in the study of blood pressures.
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