Digital Systolic Pressures in the Lower Limb in Arterial Disease

By S. A. Carter, M.D., and J. D. Lezack

SUMMARY
Systolic pressures were measured by using pneumatic cuffs on the second toe, ankle, and arm. In the absence of clinically evident peripheral vascular disease, digital pressure expressed as a percentage of the brachial pressure averaged 87% and was not significantly different in older normal persons, patients with hypertension, diabetes mellitus, or coronary artery disease from that in young normal subjects. Digital pressures were decreased in patients with arteriosclerosis and thromboangiitis obliterans, or Raynaud's phenomena. Mean digital pressures correlated well with clinical and angiographic findings. In arteriosclerosis obliterans digital pressures in the limbs with claudication averaged 43% of the brachial pressure, and in patients with rest pain or skin lesions, or both, 21%. The ankle-to-toe pressure difference was increased in the majority of patients with thromboangiitis obliterans and in some diabetics with arteriosclerosis obliterans. The results indicate that digital pressure expressed as percentage of brachial pressure is a good index of the severity of the overall occlusive process, whereas the ankle-to-toe pressure difference may provide a useful index of the disease in the small distal arteries.

Additional Indexing Words:
Diabetes mellitus
Raynaud's phenomena
Intermittent claudication
Ankle-to-toe pressure difference
Arteriosclerosis obliterans
Peripheral vascular disease
Hypertension
Thromboangiitis obliterans
Gangrene
Rest pain

SYSTOLIC PRESSURE measured at the level of the ankle in limbs with arterial occlusive disease (AOD) correlates well with associated clinical and angiographic findings, and as has been shown previously, it provides a valuable tool for the assessment and follow-up of patients.1-4 Ankle pressure, however, does not reflect arterial disease which may be present in the small vessels distal to the ankle. In limbs which come to amputation, occlusion of the larger proximal arteries is often accompanied by an occlusive process in the arteries of the foot.5,6 Such distal occlusions may be an important factor in the development of skin lesions in the toes of patients with arterial disease. The systolic pressure measured in the digits should reflect the occlusive process in the distal vessels. Low digital systolic pressure and an increase in brachial-to-toe pressure difference were reported in patients with AOD by Conrad and Green,7 but their data do not provide information on the vessels of the foot distal to the ankle since no pressure gradients along the involved limbs were reported.

We previously reported on the effect of changes in vasomotor state on systolic pressure in the toe and on the ankle-to-toe pressure difference in young normal subjects.8 This study compares systolic pressure in the toes and the ankle-to-toe pressure difference in patients with and in several groups of subjects without clinically evident peripheral arterial disease. The latter groups include young and

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Table 1

Age and Blood Pressure in the Groups Studied

<table>
<thead>
<tr>
<th>Subjects</th>
<th>No vascular disease</th>
<th>Vascular disease</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young normal</td>
<td>Older normal</td>
</tr>
<tr>
<td>Subjects</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>21 ± 4*</td>
<td>52 ± 6</td>
</tr>
<tr>
<td>Brachial pressure (mm Hg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>117 ± 8*</td>
<td>135 ± 22</td>
</tr>
<tr>
<td>Diastolic</td>
<td>70 ± 8*</td>
<td>78 ± 9</td>
</tr>
</tbody>
</table>

*Mean ± standard deviation.
occlusive processes distal to the popliteal artery, and nine of the 11 had arterial disease distal to the brachial artery. Nine patients had thrombophlebitis. Angiographic confirmation of the occlusive process was available in 102 of the 218 limbs examined in patients with AOD.

**Techniques**

**Angiography**

Angiography was carried out by the translumbar or retrograde femoral route. The details of the technique and the criteria for the classification of the occlusive and stenotic lesions were reported previously.

**Determination of Systolic Pressures**

Systolic pressures were determined in the second toe during deflation of a pneumatic cuff, 2 cm wide, applied to the base of the digit. The cuff was constructed of Penrose drainage tubing backed by adhesive tape. The pressure in the cuff at the time of resumption of arterial inflow into the digit distal to the cuff was taken as the systolic pressure. The resumption of arterial inflow was detected either by the appearance of a pink “flush” in the skin of the digit, previously blanched by tight application of rubber dam, or by the increase in the volume of the digit recorded by means of a mercury-in-rubber strain-gauge plethysmograph applied to the terminal phalanx. Figure 1 shows the agreement between systolic pressures obtained by the two methods in 20 limbs with and 7 without AOD.

Pressures at the ankles were determined by using a cuff 15.5 cm wide. The end point was detected by the flush technique, capacitance pulse-pickups, or an ultrasonic flow detector. Good agreement has been reported among these methods, and the reproducibility of the ankle pressure has been shown to be comparable to the reproducibility of the brachial systolic pressure obtained by using the auscultatory technique. Brachial pressures were determined by auscultation immediately after each determination of pressure in the lower limb. To obtain a better index of arterial disease than that provided by the absolute values of the digital pressure, systolic pressures in the toes were calculated as a percentage of brachial systolic pressure which was taken to represent the pressure proximal to the occlusive process. This calculation was necessitated by the fact that in many patients with AOD, systolic pressures in the toes were within normal range as a result of a certain degree of systemic hypertension evidenced by elevated brachial systolic pressure. This percentage was used as the index of the overall occlusive process proximal to the toes. To assess separately the occlusive process in small distal arteries of the lower limb, the difference between the systolic pressure at the ankle and at the toe (A-T difference) was used.

Reproducibility of the measurements of digital pressures was compared with the reproducibility of the brachial pressures in studies repeated at intervals of 6 to 246 days (average 49 ± sd 56 days) in 48 limbs of 34 patients. The average differences between the two measurements and standard deviations were: 15 ± 11 mm Hg and 9 ± 8% of the brachial pressure for the systolic pressures at the toes, and 15 ± 14 mm Hg for the brachial systolic pressure. These data indicate that the reproducibility of the digital pressure is similar to the reproducibility of the brachial systolic pressure measured by auscultation. The rather large overall variability is related in large part to long intervals or unrelated surgical operations between measurements in many comparisons. In 44 of 48 limbs the digital pressure was on both occasions either within or outside the normal limits.

**Experimental Procedure**

Pressures were measured in one or both lower limbs while the subject was in the supine position. The subject's trunk was covered by an electric blanket to prevent excessive body cooling. The measurements were begun at least 1 hour

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**Figure 1**

Comparison of the measurements of systolic pressure using mercury-in-rubber strain-gauge plethysmograph and the “flush” technique in the same digits. The continuous line is the line of identity; the interrupted lines indicate differences of 10 mm Hg.

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pressures were significantly lower in all the groups with peripheral vascular disease than in the control group except for the patients with primary Raynaud’s disease limited to the upper extremities. In the group with ASO, the pressures were lower in limbs with pain at rest, or lesions of the skin, or both, than in the limbs with intermittent claudication ($P < 0.01$). There were no significant differences between the symptomatic limbs of diabetic and nondiabetic patients with ASO, whereas in the limbs without symptoms the digital pressure expressed as a percentage of the brachial pressure was significantly lower in the diabetics ($P < 0.025$).

Despite the significant differences between the groups with and without AOD, there was considerable overlap of absolute values of digital systolic pressures. In 38% of the symptomatic limbs with AOD, the digital systolic pressures were within the 95% confidence limits of the control group. When the pressures were expressed as percentage of brachial systolic pressure, this percentage was reduced to 6% and thus the overlap was largely eliminated. Figure 2 shows the results in the limbs with various degrees of disease according to angiographic criteria. The pressures were below normal in all but two of 56 limbs with complete occlusion, in 21 of 25 limbs with severe, and in 13 of 21 limbs with mild stenosis. The mean systolic pressures correlated well with the severity of the lesions as determined by the angiographic findings with lower pressures in the groups with more extensive disease. There was, however, no

Table 2

| Systolic Pressures in the Lower Limbs in Groups Without Peripheral Vascular Disease |
|---------------------------------|--------|---------|---------------|---------------|---------------|
|                                 | Young normal | Older normal | Diabetes mellitus | Coronary artery disease | Hypertension |
| Systolic pressure               |          |         |               |                  |              |
| Digital (mm Hg)                 | 16       | 12      | 10            | 7               | 15           |
| Digital % of brachial           | 100 ± 4* | 120 ± 8† | 120 ± 11      | 100 ± 7         | 149 ± 6‡     |
| Ankle minus digital (mm Hg)     | 86 ± 3   | 91 ± 4  | 83 ± 4        | 87 ± 4          | 81 ± 3       |

*Mean ± standard error of mean.
†$P < 0.05$ for difference from the young normal group.
‡$P < 0.01$ for difference from the young normal group.

Results

Table 2 shows the results in the groups without peripheral vascular disease. There was no difference between the absolute values of the systolic pressure in the toes of the young normal subjects and the patients with coronary artery disease. The older normal subjects and the patients with diabetes mellitus had higher pressures in the toes than the young subjects; this increase reflects the higher brachial pressures in these groups. The digital pressure in the group with hypertension was significantly higher than in the other groups. When digital pressure was expressed as a percentage of the brachial systolic pressure, there were no significant differences among the groups including the hypertensive patients. The ankle-to-toe (A-T) pressure difference was significantly higher in the hypertensive patients than in the other groups without overt peripheral vascular disease, but there were no significant differences among the other groups. In the comparisons which follow, the young and older “normal” subjects and the patients with diabetes mellitus or coronary artery disease but without overt peripheral vascular disease were combined and are referred to as the control group.

Table 3 shows the mean digital systolic pressures, given in millimeters of mercury and as a percentage of brachial systolic pressure, in patients with overt peripheral vascular disease and in the control group.
significant difference between the limbs with single occlusion and severe stenosis.

Figure 3 shows the A-T differences in various patient groups. With few exceptions, these differences were within normal limits in the groups with Raynaud's phenomena and in arteriosclerosis obliterans without diabetes. The mean A-T differences for these groups were not significantly different from those of the control group. On the other hand, the differences were above normal in 23% of limbs of diabetic patients with arteriosclerosis obliterans. In the diabetics, the mean A-T differences were significantly higher in the limbs with rest pain, or lesions, or both (P < 0.005), and in the asymptomatic limbs (P < 0.025) than in the control group. In the limbs with intermittent claudication, the mean A-T difference was also higher than in the control group, but the means were not significantly different. Approximately half of the patients with increased differences were normotensive. In patients with thromboangiitis obliterans the A-T differences were above normal in 11 of 14 symptomatic limbs and in three of seven asymptomatic limbs. In all subgroups with thromboangiitis, the mean differences were significantly greater than in the control group (P < 0.001). All patients with thromboangiitis, with one exception, were normotensive.

**Discussion**

Systolic pressures in the toes have not been studied extensively. We reported previously that in young healthy subjects systolic pressure at the toe averaged 81 ± 15 mm Hg during body heating and 104 ± 16 mm Hg during body cooling. In the present study the pressure averaged 110 ± 26 mm Hg under normal resting conditions in a group of subjects of various ages without clinical evidence of peripheral vascular disease. The higher average and greater variability of digital pressures in the present study probably reflect the somewhat higher values and greater range of the systolic arterial pressure in the older subjects in the group as evidenced by the brachial systolic pressure. Systolic pressure
Figure 2

Systolic pressures in the toes as percentage of the brachial systolic pressure in groups of limbs according to the angiographic findings. The normal range represents the 95% confidence limits of the control group without arterial disease.

at the toe was lower than brachial systolic pressure in 38 of 45 subjects without peripheral vascular disease (PVD) and averaged 87% of the brachial systolic pressure. This relationship is similar to that found in a young healthy group during body heating and cooling but differs from the results of Conrad and Green who reported the absence of a difference between the brachial and toe pressures in normal subjects before and after oral administration of alcohol. Their findings are probably due to the use of a narrower, 1-cm wide, cuff. Cuffs which are too narrow in relation to the circumference of the digit have been reported to overestimate systolic pressures in the digits of both lower and upper limbs. The average A-T difference of 38 \(\pm\) 15 mm Hg in the group without PVD under normal resting conditions is intermediate between the values of 34 and 46 mm Hg reported for young healthy subjects during body cooling and heating, respectively.

In the absence of clinical PVD, the relationship of the digital pressure to the pressures measured in the arm and at the ankle was the same in the older healthy subjects and patients with diabetes mellitus or coronary artery disease as in the young healthy subjects. If it is assumed that there are no great differences in resting blood flow in the feet among these groups, then the finding of similar pressures suggests that age, diabetes, and coronary artery disease per se do not lead to a hemodynamically significant encroachment on the lumen in the arterial tree proximal to the toes.

In the hypertensive group without PVD, the relationship of the systolic pressure at the toe to the brachial pressure was similar to that in the normotensive group without PVD, but the digital systolic pressure and the A-T difference were higher. Thus in the hypertensive subjects the ankle pressure increases more than the brachial and digital pressures. The increased A-T difference corresponds to the increased difference between the brachial and finger systolic pressures reported in patients with hypertension. It appears that the increase in systolic pressure as the arterial pressure wave travels from the heart to the vessels of the limbs is greater in hypertension. However, once the wave reaches smaller arteries such as those of the hand and foot, the systolic pressure falls more than in subjects with normal blood pressure. These findings can be explained by the higher resistance and the small diameter of the peripheral vessels. Increased peripheral resistance increases reflection of the arterial pressure wave and causes greater increase in the systolic pressure proximal to the hand and foot (Carter SA; Unpublished data). Once the pressure wave reaches the arteries of the hand and foot, their smaller diameters result in greater damping and, therefore, in a greater drop in the systolic pressure.

In patients with Raynaud’s phenomena affecting the lower limbs, in both the group with primary Raynaud’s disease and the group with systemic disease, as well as in those with systemic disease in whom the phenomena were present only in the upper limbs, the systolic pressure at the toe was lower than in the control group both in absolute value and in relation to the brachial pressure. These
findings agree with the results of Conrad and Green.\(^7\) Also the A-T difference was greater than in the control group although the difference was not statistically significant. The lower digital pressures could be due to structural narrowing or occlusion in the small arteries of the foot or to their smaller diameter resulting from increased contraction of the vascular smooth muscle. It is likely that both factors are operating. Alcohol taken orally decreases the brachial-to-toe pressure difference in patients with vasospasm;\(^7\) this observation suggests a functional element. There is also angiographic evidence of structural changes in the small arteries of patients with long-standing Raynaud's phenomena.\(^{21}\)

In groups with AOD, systolic pressures at the toe were lower in absolute value and in relation to the brachial pressure than in the control group. This was true even in many limbs without symptoms. However, the digital pressure expressed as percentage of the brachial pressure proved to be a better index of the occlusive process since it largely eliminated the overlap with the control group which was present in the absolute values of the pressures. Systolic pressure at the toe of less than 64% of the brachial pressure is abnormal. The digital pressures correlated well with angiographic findings, and in patients with ASO the digital pressure also correlated with the severity of the symptoms.

\(\text{Figure 3}\)

Differences in systolic pressure between the ankle and the second toe in limbs with arterial disease. The upper limit of normal represents the upper limit of 95% confidence of the control group without arterial disease. Limbs of patients with brachial systolic pressure of less than 170 mm Hg are represented by the filled dots, those of patients with higher pressures by the x's. In the group with Raynaud's phenomena, the filled triangles represent the limbs of patients with primary Raynaud's disease; the open triangles indicate limbs of patients with secondary Raynaud's phenomena. Int. Claud. = intermittent claudication.
The digital pressure averaged 60 to 70 mm Hg in the limbs with intermittent claudication and 30 to 35 mm Hg in those with pain at rest, lesions of the skin, or both, in patients with and in those without diabetes mellitus. The lack of difference between diabetic and nondiabetic patients suggests that the severity of symptoms in both groups depends primarily on the overall occlusive process proximal to the toes which is reflected in the digital pressures. The findings are also consistent with the lack of difference between diabetics and nondiabetics in the occlusive process in smaller more distal vessels 10 to 250 microns in diameter, and they suggest that histologic changes of microangiopathy reported in the capillaries and arterioles of diabetics are not important in the causation of symptoms. The digital pressures averaged 25 to 30 mm Hg in symptomatic limbs of patients with TAO and were as low in the limbs with intermittent claudication as in those with more severe symptoms. The reason for this finding is not clear. Possibly a more severe occlusive process may be required in TAO before any symptoms occur since the disease is almost exclusively below the popliteal artery where there are two or three vessels in parallel, any one of which might provide adequate blood flow to the distal muscles during exercise.

Digital systolic pressures of less than 20 mm Hg were encountered in 20 limbs with pain at rest or lesions of the skin, or both, and in eight of the 20 limbs they were less than 10 mm Hg. These values are similar to those reported in the limbs which came to amputation. Since critical closing pressures of more than 20 mm Hg have been reported in the human finger, the very low digital pressures in the toes in some limbs with AOD in the supine position indicate that critical closure may be important in the development of pain at rest and gangrene. In such patients, putting the limbs in the dependent position is essential since the digital pressures increase with an increase in hydrostatic pressure and blood flow is increased.

With few exceptions, the A-T differences were not increased in the limbs of nondiabetic patients with ASO. Increased gradients were found in the diabetics with ASO and occurred often in limbs with pain at rest, or lesions of the skin, or both. About half of the diabetic patients with increased A-T differences had hypertension.

Since hypertension alone may be associated with increased A-T differences, it is difficult to judge with certainty to what extent the increased A-T difference is due to occlusion in the distal vessels as opposed to increased peripheral resistance associated with hypertension. Increased A-T differences can be due to the occlusive process in the arteries of the foot between the ankle and the toes. We also encountered them in the limbs with angiographically documented occlusion of the anterior and posterior tibial arteries but in which the peroneal artery was not diseased. In such limbs the pressure at the ankle is normal whereas the digital pressure is decreased. The increased A-T difference in some limbs of the diabetics with severe occlusive disease fits with the pathologic finding of greater severity of the occlusive process in the arteries distal to the popliteal in the patients with diabetes mellitus. Although diagnostic arteriograms and the pressure measurements in living patients suggest a tendency for more occlusion of the vessels of the foot itself in the diabetics, this is not supported by pathologic studies on amputated limbs. This discrepancy might be due to a different distribution of lesions in the amputated limbs. Indeed, it has been suggested that more extensive occlusions may be present in the limbs which do not come to amputation, if there is sufficient time for development of collateral circulation. In the group with TAO increased A-T differences were found in the majority of symptomatic limbs and in some limbs without symptoms. This finding fits with the well-documented involvement of the arteries of the leg and foot in TAO. As was previously shown, A-T pressure differences vary with blood flow, but even in young healthy subjects during vasodilatation they are always below 70 mm Hg. Therefore, in the absence of systemic hypertension, the finding of an A-T difference
greater than 70 mm Hg under normal resting conditions, strongly suggests the presence of an occlusive process in the small distal arteries of the limb. The finding of a normal A-T difference, on the other hand, does not rule out an occlusive process in the small distal vessels, because a normal A-T difference might occur in the presence of distal disease if the blood flow is low.

The reported results are based on measurements of pressure in the second toe. It is a common clinical finding in arteriosclerosis, thromboangiitis obliterans, and in Raynaud's phenomena, that pain, coldness, discoloration, or lesions of the skin are present in one or more toes, while other toes are unaffected. This indicates that the arteries supplying individual digits may be affected by the disease. Thus, although abnormal digital pressure signifies the presence of arterial disease, a normal pressure in one digit does not rule out disease of the arteries supplying the others. The third, fourth, and fifth toes are usually so short that there is insufficient length of the digit distal to the cuff to allow determination of the systolic end point. The hallux is of sufficient length, but because of its greater width a 3-cm wide pneumatic cuff should be used for the measurements. We measured pressures in the hallux in 193 limbs with and without overt peripheral arterial disease in the series reported above. The mean pressures between the hallux and the second toe did not differ significantly (mean difference, 1.6 mm Hg). In 92% of the comparisons the pressures in the two digits were either both below normal or were both within normal limits. Therefore, although in most cases the results agree, a somewhat larger number of abnormalities will be detected if the pressure is measured in both digits.

The results of this study indicate that digital pressure expressed as a percentage of brachial pressure is a good index of the severity of the occlusive process since it correlates well with the clinical and angiographic data. Digital pressures, as well as ankle pressures, strongly suggests the presence of an occlusive process in the small distal arteries of the limb. The finding of a normal A-T difference, on the other hand, does not rule out an occlusive process in the small distal vessels, because a normal A-T difference might occur in the presence of distal disease if the blood flow is low.

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The results of this study indicate that digital pressure expressed as a percentage of brachial pressure is a good index of the severity of the occlusive process since it correlates well with the clinical and angiographic data. Digital pressures, as well as ankle pressures, therefore, should be of value in the assessment and follow-up of patients with AOD. However, since gangrene frequently starts in the toes, digital pressures may indicate more accurately than ankle pressures the possibility that a lesion will develop and the prognosis for limbs with preexisting lesions. Because TAO and diabetic ASO are known to involve preferentially small distal arteries of the limb, the finding of increased A-T differences in the majority of limbs of patients with TAO and in some limbs of diabetic patients with ASO suggests that measurement of A-T differences will provide a useful index of the occlusive process in the smaller distal vessels.

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References


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