Direct Blood Pressure Measurements in Brachial and Femoral Arteries in Children

By Myung K. Park, M.D., and Warren G. Guntheroth, M.D.

SUMMARY
Intra-arterial pressure in the brachial artery was compared with that in the femoral artery in children. There were no significant differences in systolic, diastolic, or mean pressures. The average auscultatory systolic pressure in the arm, obtained with a cuff 20% wider than the limb, was identical to the average direct systolic pressure in the brachial and femoral arteries. The auscultatory systolic pressure in the leg, using the same criterion for cuff width, was 11 mm Hg higher than the direct pressures. The discrepancy could represent (1) a systematic error in cuff size of inadequate width or length or (2) additional systolic amplification between the femoral and popliteal arteries. Since the femoral pressure is widely used in cardiac catheterization, this pressure is suggested as the standard for calibrating auscultatory technics. For leg blood pressure measurements a cuff at least 25% wider than the average leg diameter and long enough to encircle the limb is recommended.

Additional Indexing Words:
Aging: effect on blood pressure
Pressure pulses, transmission characteristics
Hypertension
Standing waves
Systolic amplification

The diagnosis of mild hypertension in children rests upon an accurate determination of the blood pressure in the arm in relation to normal standards, and the diagnosis of coarctation of the aorta requires accurate determination of blood pressure in both arms and legs.

It is generally believed that the systolic blood pressure in the legs is significantly higher than that in the arms in adults as well as in children. However, Pascarelli et al. studied consecutive and simultaneous direct blood pressure measurements in arms and legs in normal adults and in patients with aortic insufficiency and reported that all components of the blood pressures in the brachial and femoral arteries were essentially the same. The average age of their patients was 55 years. O'Rourke and colleagues found a marked decrease in amplification of the systolic pressure in the iliac artery as compared to that in the aortic arch in subjects in this age group, whereas children demonstrated four or five times more systolic amplification. Nadas stated that systolic amplification in the legs, due to reflected waves, accounts for a higher pressure in the legs than arms. It is, then, uncertain that the results of Pascarelli would apply in children, and there are no reports on the simultaneous or consecutive measurements of blood pressures in the arms and legs by direct arterial puncture technic in children.

The purpose of this study was to establish whether any disparity in the various components of blood pressure measurements exists in children by direct intra-arterial technic and to correlate the arterial pressures with those obtained by standard auscultatory technic.

Methods
Forty-one sets of blood pressure determinations were obtained by direct arterial puncture on 37
patients who were undergoing diagnostic cardiac catheterization at the University of Washington Hospital. The patients ranged from 3 to 15 years of age and had various types of congenital heart disease. Patients with angiographic evidence of severe aortic stenosis or coarctation of the aorta were excluded from the study. In four patients, blood pressures changed substantially while the needles were in place due to excitement, and two sets of measurements from them are included in the analysis.

The patients were sedated in the usual manner with a meperidine-promethazine-chlorpromazine mixture 45 to 60 min prior to the procedure. The right brachial artery was isolated under 1%-lidocaine infiltration in the mid-upper arm or in the antecubital fossa, as part of our routine cutdown procedure for right heart catheterization. The groin of the same side was infiltrated with 1% lidocaine at the same time. After completion of the heart catheterization, arterial punctures were made in the exposed brachial artery using a 21 or 22-gauge short bevel needle and in the femoral artery using a 20-gauge needle with stylus. (Only a single puncture of the artery was permitted.) The needles were the same length. The polyethylene connecting tubes for the pair of needles were 1 mm in internal diameter and were of matched length (25 to 35 cm). The pressure was recorded with a P23Db Statham strain-gauge pressure transducer connected to a Honeywell recorder, at a paper speed of 25 mm/sec. The frequency response of the system was accurate to 50 Hz. The pressures were recorded consecutively, switching back and forth on the same transducer. Zero reference point was taken at the level of mid-thorax.

For comparison, auscultatory blood pressures were obtained from the patients' charts, retrospectively. These pressures were recorded by the resident physician the day prior to cardiac catheterization, without sedation, in the supine position. Cuff sizes were chosen as close as possible to 20% wider than the average diameter of the limb. The stethoscope was placed over the antecubital fossa for the arm, and the popliteal fossa for the leg. (We could obtain all values on only 28 patients, so that the means presented below vary slightly from those concerned only with direct pressure measurements.)

The values were punched on IBM cards. The Massey XTAB program, Plot one,11 was employed to determine the means, correlation coefficients, standard deviations, and to generate scattergrams. Paired-sample t-tests were performed with an Olivetti 101 programmed calculator.

Results

The average systolic pressures in the brachial and femoral arteries were essentially identical with a correlation coefficient of 0.904 (fig. 1). The systolic pressure in the brachial artery (BA) averaged 104.90, compared to 104.85 in the femoral artery (FA) (table 1).

The average diastolic pressure in the BA was 57.32 and the corresponding value for the FA was 57.17. The correlation coefficient was 0.918 (fig. 2). Obviously, the group means are not significantly different.

The group average of the mean pressures in the BA was 76.14, compared to the average pressures of Brachial

![Figure 1](http://circ.ahajournals.org/content/72/2/232.f1)

**Figure 1** Scattergram of the systolic pressures in the brachial and femoral arteries. The correlation coefficient is 0.904. The regression equation is \( Y = 104.90 + 0.993 (X - 104.85) \).

**Table 1**

Comparison of Arterial Pressures in the Brachial and Femoral Arteries: 41 Sets of Data*

<table>
<thead>
<tr>
<th>Arterial pressures (mm Hg)</th>
<th>Systolic Mean</th>
<th>Diastolic Mean</th>
<th>Mean Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Systolic</td>
<td>Diastolic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>sd</td>
<td>Mean</td>
</tr>
<tr>
<td>Brachial artery</td>
<td>104.90</td>
<td>16.72</td>
<td>57.32</td>
</tr>
<tr>
<td>Femoral artery</td>
<td>104.85</td>
<td>15.22</td>
<td>57.17</td>
</tr>
</tbody>
</table>

*There are no significant differences between group means, using paired-sample t-test \((P > 0.1)\).
for the FA of 76.55. The correlation coefficient was 0.965 (fig. 3).

Auscultatory and direct arterial pressures are compared in table 2. The group means for the arm (auscultatory), brachial artery, and femoral artery were all 104 mm Hg, whereas leg auscultatory pressure was 115. Paired-sample t-tests yielded highly significant differences between the latter group and the other three groups (P < 0.01).

Discussion

Most pediatricians have agreed that, in children as in the adults, the systolic pressure in the leg is higher than that in the arm.\(^1\), \(^4\)–\(^7\), \(^12\)

In contrast, our study indicates that there is no difference in the various components of blood pressure (systolic, diastolic, and mean) between the brachial and femoral arteries, although the auscultatory pressures in the leg were higher when standard technics were used. To be comparable to the arm, the arterial pressure in the leg would have to be obtained at the popliteal fossa. However, during cardiac catheterization, with the patient supine, the femoral artery just below the inguinal ligament is the only artery in the lower extremity ordinarily studied. At the least, there is an obvious question raised by our data as to the meaning of a subject's "blood pressure."

The systolic pressure in the leg, whether obtained by needle or auscultation, is higher than that found in the aorta. This phenomenon of systolic amplification is well known.\(^3\), \(^13\), \(^14\) It has been suggested that systolic amplification does not occur in the brachial artery, accounting for the normally lower systolic pressure in the arm.\(^5\) However,

![Figure 2](image1)

**Figure 2**

Scattergram of the diastolic pressures in the brachial and femoral arteries. The correlation coefficient is 0.918. The regression equation is \(Y = 57.32 + 0.932 (X - 57.17)\).

![Figure 3](image2)

**Figure 3**

Scattergram of the mean pressures in the brachial and femoral arteries. The correlation coefficient is 0.965. The regression equation is \(Y = 76.14 + 0.956 (X - 76.55)\).

Table 2

Comparison of Systolic Pressures by Auscultation and Arterial Puncture in Upper and Lower Extremities (Mean and Standard Deviation): 28 Sets of Data*

<table>
<thead>
<tr>
<th>Pressure (mm Hg)</th>
<th>Arm</th>
<th>Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>By auscultation</td>
<td>103.64</td>
<td>115.19</td>
</tr>
<tr>
<td></td>
<td>± 8.80</td>
<td>± 14.93</td>
</tr>
<tr>
<td>By direct puncture</td>
<td>103.68</td>
<td>103.96</td>
</tr>
<tr>
<td></td>
<td>± 15.38</td>
<td>± 14.99</td>
</tr>
</tbody>
</table>

*There are no significant differences between means except for leg pressures obtained by auscultation, which are higher than the other three (P < 0.01).
Intra-arterial pressure recorded at four sites on withdrawal of an N.I.H. angiocardiographic catheter (side holes) from ascending aorta to the brachial artery in an 8-year-old boy. There is distortion of the wave shape as well as systolic amplification.

our study supports earlier reports that systolic amplification also occurs in the brachial artery.\textsuperscript{13, 15} Figure 4 illustrates this amplification. The record is obtained during the withdrawal of a side-hole catheter from the ascending aorta to the brachial artery. The peak systolic pressure rises 10 to 12 mm Hg.

The cause of amplification of the systolic pressure in peripheral arteries remains uncertain. It was attributed by Hamilton and Dow\textsuperscript{16} to standing waves and subsequently, to a more general concept, reflected waves from the terminal arterioles.\textsuperscript{10, 14, 17, 18} Figure 5, reproduced from Wiggers,\textsuperscript{19} presents the concept of summation of the forward wave and the rebound wave. There is a curious problem with this concept: For summation to occur, transmission of the rebound wave from the recording site to the periphery and back would require infinite velocity, whereas most actual measurements of phase velocity range from 3 to 6 m/sec.\textsuperscript{10, 20, 21} This is not to deny reflected waves, but to question whether they constitute the major source of systolic amplification.

Taylor\textsuperscript{22} suggested that systolic amplification represents a fundamental characteristic of transmission of waves in a non-uniform system. The crucial non-uniformity is an impedance mismatch between the low impedance elastic aorta and the high impedance muscular arteries in the periphery. Figure 6 shows a dramatic amplification occurring abruptly at the level of the iliac artery in a dog. At this level the elastic-collagen ratio reverses from its value of greater than one for the aorta.\textsuperscript{22}

With aging there is generally less systolic amplification, which O'Rourke and his co-authors\textsuperscript{10} attribute to a "decline in peripheral reflection coefficient resulting from decreased distensibility of peripheral arteries with age." On the basis of the work of Taylor,\textsuperscript{22} it is more likely that the cause is a loss of elasticity in the aorta, causing a "better" impedance match with the peripheral arteries.

Finding a higher auscultatory pressure in the leg than by direct puncture of the femoral artery in our study suggests two alternative
Figure 6

Recording from a young dog under morphine and pentobarbital anesthesia. An N.I.H. angio-catheter is gradually withdrawn from the aortic arch into the iliac artery. Reference tracings are from the brachial artery, respiration with a pneumograph and lead II electrocardiogram.
explanations: (1) The recommended cuff width for the leg is inadequate, or (2) there is additional systolic amplification below the femoral puncture site, which causes a true increase at the popliteal fossa. At present there is insufficient data to decide between these alternatives, but considering the widespread use of the femoral artery pressure in diagnostic procedures, femoral pressures could reasonably be taken as the standard and the auscultatory technic altered to conform. At present, the overestimate by auscultation amounts to 11 mm Hg.

The most common recommendation for blood pressure cuff is to cover two thirds of the upper arm with the cuff. This recommendation ignores variations in fatness of the subject, and we feel that the current recommendation of the American Heart Association is superior; in other words, that the bag should be 20% wider than the diameter of the limb. This is generally in accord with our experience and with that of Moss and Adams for the arm, although the latter used a somewhat more complicated formula involving circumference and age. Obviously, relating the cuff size to the limb diameter requires a wider cuff for the leg. On the basis of our present study, we suggest use of a leg cuff that is at least 25% wider than the average diameter of the thigh, and one with an air bladder long enough to encircle the limb.

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Foetal Circulation — Harvey 1628

. . . For the right receiving the blood from the ear, thrusts it forth through the vena arteriosa, and its branch called canalis arteriosus, into the great artery. Likewise, the left at the same time by the mediation of the motion of the ear, receives that blood, which is brought into the left ear through that oval hole from the vena cava, and by its tention and constriction thrusts it through the root of the Aorta into the great artery likewise. So in Embryons whilst the lungs are idle, and have no action nor motion (as if there were none at all) Nature makes use of both the ventricles of the heart, as of one for transmission of blood. And so the condition of Embryons that have lungs and make no use of them, is like to the condition of those creatures which have none at all. —The Anatomical Exercises of Dr. William Harvey; De Motu Cordis 1628; De Circulatione Sanguinis 1649 (first English text). Edited by Geoffrey Keynes. London, The Nonesuch Press, 1653, p. 46.
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Circulation. 1970;41:231-237
doi: 10.1161/01.CIR.41.2.231

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