Comparison of Simultaneously Recorded Central and Peripheral Arterial Pressure Pulses During Rest, Exercise and Tilted Position in Man

By Edwin J. Kroeker, M.D. and Earl H. Wood, M.D., Ph.D.

Central (aortic or subclavian), brachial, radial and femoral pressure pulses were recorded simultaneously in 12 healthy subjects during conditions of rest, exercise and 70 degree head-up tilt. Peripheral systolic pressure at rest uniformly exceeded the central systolic pressure generated by the same heartbeat. The average radial pulse pressure was 146, 146 and 165 per cent of central pulse pressure during rest, exercise and tilt while radial mean pressures were 94, 93 and 98 per cent of central mean pressures respectively. Summation of the incident pulse wave with reflected waves from the periphery and resonance effects in the peripheral arterial systems may produce these changes in pressure and contour.

ALTHOUGH measurements of blood pressure in man by direct needle puncture are now commonplace, actually, determinations of arterial pressure by this technic are of relatively recent origin. The average and range of values encountered in man, especially in regard to central arterial pressure pulses, have not as yet been well documented.

Direct arterial blood pressure was first recorded in man during limb amputations. Thus, Faivre in 1856 reported the blood pressure in the femoral artery of man as being 120 mm. of mercury. Merke and Müller in 1925, surgically exposed a brachial artery in each of two critically ill patients and inserted T tubes for the recording of pressures. Brachial arterial pressures were obtained by needle puncture in 1931 by Wolf and von Bonsdorff in a series of normal subjects and of patients with cardiovascular disease. Hypodermic-type manometers were used to record simultaneous pressure pulses in the axillary, femoral and dorsalis pedis arteries by Hamilton and co-workers in 1936. Aortic and radial arterial pressure pulses were recorded simultaneously by Fuller and associates in 1952 during an operation for coarctation of the aorta.

Using the technic of arterial catheterization, Schnabel and co-workers in 1952 reported measurements of the central pressure pulse in the intact human.

The present investigation was initiated for the purpose of establishing normal pressure-pulse data in man by the simultaneous recording of central and multiple peripheral arterial pressure pulses during conditions of rest, exercise and 70-degree head-up tilt.

METHODS

The studies included 14 arterial catheterizations of 12 healthy male physicians whose average age was 32 years (range: 27 to 41), average height was 70 inches (range: 66 to 74) and average weight was 175 pounds (range: 150 to 205) (table 1). Subjects were supine during rest and exercise; however, during exercise the left foot was in the pedal of a bicycle ergometer, while the right leg, with an indwelling needle in the femoral artery in the right groin, remained at rest. The subject maintained exercise at a rate of approximately 45 r.p.m. with his left leg by watching a tachometer leading from the bicycle ergometer. Arterial pressure pulses at multiple sites were recorded at rest, after 3 to 6 minutes of exercise and after at least 10 minutes in the 70-degree head-up tilt position. Respiration and the electrocardiogram were registered simultaneously. Cardiac output was measured by the...
direct Fick technic or by the dye-dilution technic, under all three conditions just before or after the recordings of arterial pressures.

Central arterial pressure pulses were obtained via a Peterson-type arterial catheter advanced up to the arch of the aorta or to the left subclavian artery through an 18G-gauge needle inserted into the femoral artery at the groin or into the left brachial artery in the antecubital fossa respectively. The catheter was 80 cm. in length, 1.0 mm. in external diameter and 0.5 mm. in internal diameter. The final position of the catheter tip as measured on the roentgenogram with correction for x-ray tube distortion was an average of 5.5 cm. (range: 1.5 to 9.3) from a point at the top of the aortic arch at the midternal line. The catheter was inserted an average distance of 51.5 cm. (48.5 to 54.5) in the five femoral arterial catheterizations and 42.5 cm. (40 to 45) in the nine brachial arterial catheterizations. The average distance from the third interspace at the sternum to the femoral-needle puncture site was 50 cm. (45 to 53), and from the brachial-needle puncture site 42.5 cm. (40 to 46) respectively in these subjects.

The catheter-manometer system permitted immediately interchangeable recording with a capacitance* or strain-gauge manometer. Both strain-gauge and capacitance manometer-catheter systems were optimally damped. The response of the strain-gauge manometer-catheter system to sine-wave pressure variations of increasing frequencies was within 10 per cent of static sensitivity out to 12 c.p.s., while the capacitance manometer-catheter system had a uniform response out to 60 cycles per second. It has been found that catheter-manometer systems with these characteristics are adequate to reproduce the practically important components of peripheral and central pressure pulses in man.

Peripheral arterial pressure pulses were recorded by means of a hypodermic strain-gauge manometer system described previously4,1* with a uniform response to sine-wave pressure variations up to 25 cycles per second. Dynamic response characteristics of all manometer systems to sine-wave and square-wave pressure variations were determined immediately following each procedure.16

Photokymographic recording was at paper speeds ranging from 75 to 150 mm. per second. The manometers were calibrated frequently during the course of a procedure, known pressures being projected into all the manometer systems simultaneously. The zero reference point for both the supine and the tilt position was taken as the midpoint of the anteroposterior diameter of the chest at the level of the third interspace at the sternum. Mean pressures were obtained by planimetry of the photographic record. Only simultaneously recorded pulses were measured. Simultaneous recordings of central and radial pressure pulses were obtained in all 12 subjects. In addition simultaneous brachial pressure pulses were obtained in eight and simultaneous femoral pressure pulses in nine of these 12 subjects.

**RESULTS**

The values for the 12 subjects as regards age, height, surface area, metabolic rate, heart rate, cardiac indexes, and central and radial arterial pressures are shown in table 1.

Table 2 compares central arterial pressures recorded in different conditions in healthy men. The average increase in oxygen consumption produced by the exercise was 250 (200 to 320) per cent as compared to an increase of 69 (46 to 97) per cent in the cardiac output (table 1).

Table 3 shows the relationship of peripheral arterial pressures to the pressures generated by the same heartbeat in the central arteries in healthy men. When the men were resting, in the supine position, there was a uniform increase of systolic pressure toward the periphery. The diastolic, dicrotic and mean pressures showed a smaller but uniform decrease to the periphery.

During exercise the pressure changes from the central to the peripheral arteries were similar to the changes at rest except for a greater decrement in dicrotic pressure to the brachial and radial arteries and an absence of the increase in systolic pressure at the femoral artery.

During the 70-degree head-up tilt the average percentage increase of systolic pressure was larger and the decrement in mean pressure toward the periphery was smaller than in the resting state.

Table 4 is a comparison of pulse pressures recorded from the aorta and from the femoral, brachial and radial arteries in healthy men. At rest, central pulse pressure was 45 mm. of mercury, but it increased to 57 mm. during exercise and decreased to 33 mm. at the 70 degree head-up tilt. At rest, brachial pulse pressure was 131 per cent, femoral 139 per cent and radial 146 per cent of aortic pulse pressure. During exercise there was a striking

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decrease in the degree of amplification of the pulse pressure in the femoral artery, femoral pulse pressure being only 114 per cent of aortic pulse pressure, while brachial and radial pulse pressures relative to aortic pulse pressure showed little change from the resting condition. During the 70-degree head-up tilt the absolute aortic pulse pressure was reduced but the amplification of peripheral pulse pressure in relation to aortic pulse pressure was increased at all the sites studied to levels of 146 per cent in the brachial, 159 per cent in the femoral and 165 per cent in the radial artery.

These differences in pressure levels between peripheral and central pressure pulses are associated with the characteristic differences in contour of these pulses. Figure 1 shows a series of simultaneously recorded pulses in a 31 year old healthy subject. There is a gradual increase in the time interval between the peak of the R wave in the electrocardiogram and the onset of the pulse wave and a gradual increase in pulse pressure, especially the systolic peaks, toward the periphery. The anechoic shoulder is present in the aortic pulse but barely visible in the femoral pulse. There
### Table 3.—Peripheral Arterial Pressures* as Percentages of Central Arterial Pressure Recorded Simultaneously in Healthy Men

<table>
<thead>
<tr>
<th>Pressure Pulse</th>
<th>Subjects</th>
<th>Constant</th>
<th>% of Central Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Systolic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>101-118</td>
</tr>
<tr>
<td>Brachial</td>
<td>8</td>
<td>Average</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>102-123</td>
</tr>
<tr>
<td>Radial</td>
<td>12</td>
<td>Average</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>104-119</td>
</tr>
<tr>
<td>Femoral</td>
<td>9</td>
<td>Average</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>99-107</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>91-111</td>
</tr>
</tbody>
</table>

### During exercise

<table>
<thead>
<tr>
<th>Pressure Pulse</th>
<th>Subjects</th>
<th>Constant</th>
<th>% of Central Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>103-123</td>
</tr>
<tr>
<td>Brachial</td>
<td>8</td>
<td>Average</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>95-107</td>
</tr>
<tr>
<td>Radial</td>
<td>12</td>
<td>Average</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>103-121</td>
</tr>
<tr>
<td>Femoral</td>
<td>8</td>
<td>Average</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>112-130</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>97-111</td>
</tr>
</tbody>
</table>

### During 70 degree head-up tilt

<table>
<thead>
<tr>
<th>Pressure Pulse</th>
<th>Subjects</th>
<th>Constant</th>
<th>% of Central Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>105-118</td>
</tr>
<tr>
<td>Brachial</td>
<td>8</td>
<td>Average</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>103-121</td>
</tr>
<tr>
<td>Radial</td>
<td>8</td>
<td>Average</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>112-130</td>
</tr>
<tr>
<td>Femoral</td>
<td>3</td>
<td>Average</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>99-107</td>
</tr>
</tbody>
</table>

* The average and range of distances from the needle puncture site to the midsternum at the third interspace were 50 (45-53), 42 (40-45) and 68 (60-72) cm. for the femoral, brachial and radial arterial puncture sites respectively.

### Table 4.—Relationship of Pulse Pressures Recorded Simultaneously From Different Arteries in Healthy Men

<table>
<thead>
<tr>
<th>Condition</th>
<th>Constant</th>
<th>Aortic Pulse Pressure, mm. Hg</th>
<th>(Peripheral Pulse Pressure/Aortic) X 100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subjects</td>
<td>Femoral</td>
<td>Brachial</td>
</tr>
<tr>
<td>Rest</td>
<td>12</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>139</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>118-170</td>
<td>104-150</td>
</tr>
<tr>
<td>Exercise</td>
<td>57</td>
<td>114</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>95-136</td>
<td>103-147</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Tilt</td>
<td>33</td>
<td>150</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>142-177</td>
<td>119-168</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>25-40</td>
<td></td>
</tr>
</tbody>
</table>

is a secondary wave following the primary peak but preceding the dicrotic notch in the brachial-radial system and there is an absence of this wave in the femoral-dorsalis pedis system. The incisura, sharp and short in the aortic pulse, is lost during transmission of the pulse wave peripherally. The dicrotic notch, which is drawn out and deep in the brachial-radial system, is practically non-existent in the femoral and so drawn out and
deep in the dorsalis pedis pulse that it approaches end diastolic pressures.

Figure 2 shows the transformation of the subclavian type of pulse to the brachial-radial type at graded distances from the subclavian artery near the aorta. The records have been mounted so that the R waves of the electrocardiogram are superimposed. On the left are pulses recorded by the strain-gauge manometer system and on the right those recorded by the higher-frequency capacitance manometer. Note the similarity of the pulses recorded by these two widely different manometer systems. There is an increase in the interval from the R wave of the electrocardiogram to the onset of the pulse toward the periphery; the systolic peaks, however, tend to be stationary for the first 20 cm. There is a gradual increase in amplitude, with higher systolic peaks. The anacrotic shoulder is present and similar in both systems but disappears after the 10 cm. withdrawal. In this subject preoscillations were recorded in the central pulse only by the faster capacitance manometer system and were absent after the 10 cm. withdrawal. In the subclavian artery the incisura is followed by a second negative deflection. On withdrawal these two merge and the dicrotic notch becomes progressively deeper.

Central pulse preoscillations have been classically described in the horse by Chaveau and Marey\textsuperscript{12} and in the dog by Frank.\textsuperscript{13} The first preoscillation occurring in the latter part of diastole consists of a broad positive pressure wave and was attributed by the foregoing authors to atrial systole. The second preoscillation is a short positive pressure wave occurring immediately preceding the onset of the aortic pulse. Between the two waves there is a negative deflection with a sharp peak, somewhat resembling the incisura. The genesis of these waves is still in dispute. However, Laszt and Müller,\textsuperscript{14} in simultaneous recording of left ventricular and aortic pressure pulses in dogs, found the lowest dip of the negative deflection to coincide with the rapid increase in left ventricular pressure during isometric contraction.

Preoscillations were seen in eight of the 12 healthy subjects investigated in the present study and were more clearly demarcated in recordings by the faster manometer systems.
than in recordings by the slower systems. The first preoscillation recorded in animal studies could not, however, be discerned in the records obtained. The negative V-shaped dip was most easily recognized and was usually followed by a short positive wave, which would be analogous to the second preoscillation obtained in animal studies. Preoscillations were less readily recognized during exercise than at rest but, when seen, the V-shaped dip was closer to the central pulse and the ascending limb of the pressure pulse seemed to arise from the onset of the second preoscillation. The preoscillations were most often and most clearly seen in the 70 degree head-up tilt position and then were a greater interval in advance of the ascending limb of the aortic pulse. Preoscillations were seldom seen beyond 10 cm. from the aortic arch, midsternal line.

Table 5 shows the relationship of the onset of the central pressure pulse to the peak of the R wave of the electrocardiogram and to the anacrotic wave.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Constant Value</th>
<th>Interval from Peak of R Wave to Onset of Central Pulse, Milliseconds</th>
<th>Interval from Onset of Pulse to Anacrotic Wave, Milliseconds</th>
<th>Heart Rate, Beats per Minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>Average</td>
<td>88</td>
<td>73</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>73-103</td>
<td>51-96</td>
<td>54-88</td>
</tr>
<tr>
<td>Exercise</td>
<td>Average</td>
<td>64</td>
<td>60</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>52-91</td>
<td>45-80</td>
<td>71-109</td>
</tr>
<tr>
<td>Tilt</td>
<td>Average</td>
<td>108</td>
<td>58</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>97-118</td>
<td>46-87</td>
<td>60-113</td>
</tr>
</tbody>
</table>

* Data from 10 arterial catheterizations of eight healthy men.
Table 6.—Transmission Times of Pressure Pulses Recorded Simultaneously From Different Arteries of Healthy Men

<table>
<thead>
<tr>
<th>Condition</th>
<th>Constant</th>
<th>Transmission Time*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Radial</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Rest</td>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>140</td>
</tr>
<tr>
<td>Exercise</td>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>140</td>
</tr>
<tr>
<td>Tilt</td>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>140</td>
</tr>
</tbody>
</table>

* The time interval from the peak of the R wave to the onset of the central pulse is shown in table 5.
† I = msec, from peak of R wave of electrocardiogram to onset of pulse wave.
‡ II = msec, from onset of central pulse to onset of peripheral pulse.
§ III = calculated pulse-wave velocity from central to peripheral recording site, meters per second.

Table 7.—Buildup Times of Pressure Pulses Recorded Simultaneously From Different Arteries of Healthy Men

<table>
<thead>
<tr>
<th>Condition</th>
<th>Constant</th>
<th>Interval from Onset of Pulse to Maximal Pressure, msec.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Central</td>
</tr>
<tr>
<td>Rest</td>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>118-214</td>
</tr>
<tr>
<td>Exercise</td>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>118-214</td>
</tr>
<tr>
<td>Tilt</td>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>118-214</td>
</tr>
</tbody>
</table>

By and large, these results with subjects supine and at rest are similar to the values recorded in the literature and obtained by sphygmographic means. The pulse-wave velocity to the radial artery averaged 8.8 meters per second, to the brachial artery 7.2 meters per second and to the femoral artery 6.3 meters per second. Pulse-wave velocity from the brachial artery at the antecubital fossa to the radial artery at the wrist averaged 12.5 meters per second.

There was little change in the transmission time to the radial and brachial arteries during exercise and tilt. However, the average pulse-wave velocity to the femoral artery increased by 1.5 meters per second during exercise, and the pulse-wave velocity from the brachial to
Table 8.—Systolic Times of Pressure Pulses Recorded Simultaneously From Different Arteries of Healthy Men

<table>
<thead>
<tr>
<th>Condition</th>
<th>Constant</th>
<th>Interval from Onset of Pulse Wave to Dicrotic Notch, msec.</th>
<th>Heart Rate, Rest/min.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Central</td>
<td>Radial</td>
<td>Brachial</td>
</tr>
<tr>
<td>Rest</td>
<td>Subjects</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>311</td>
<td>330</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>296-321</td>
<td>310-344</td>
</tr>
<tr>
<td>Exercise</td>
<td>Subjects</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>271</td>
<td>296</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>228-298</td>
<td>244-325</td>
</tr>
<tr>
<td>Tilt</td>
<td>Subjects</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>231</td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>210-244</td>
<td>211-272</td>
</tr>
</tbody>
</table>

the radial artery increased by an average of 1.6 meters per second during the tilt.

Table 7 gives the buildup times of pressure pulses recorded simultaneously in healthy men. The average buildup time (onset of pulse to maximal pressure) of the central pulse was longest at rest (166 msec.), shorter during exercise (121 msec.) and shortest during the tilt (100 msec.). The buildup times of the peripheral pulses were uniformly shorter than the buildup times of the central pulses generated by the same heart beats. At rest, the average buildup time of radial pulses was 102 msec., of brachial pulses 100 msec. and of femoral pulses 138 msec. During exercise and the 70-degree head-up tilt, shortening of the buildup time peripherally persisted but to a lesser degree.

Table 8 shows systolic times of pressure pulses recorded simultaneously from different arteries of healthy men during conditions of rest, exercise and 70 degree head-up tilt. All times were measured from the onset of the pulse wave to the lowest dip in pressure of the incisura or dicrotic notch. In the femoral pulses, in which the dicrotic notch is poorly defined, the descending limb of the primary peak was extended to meet the extension of a line from the ascending slope of the undulation following the primary peak.

Central systolic time was longest at rest (311 msec.), shorter during exercise (271 msec.) and shortest during the 70 degree tilt (231 msec.). The shortening of the systolic time during the tilt did not seem to be related merely to the heart rate, for the heart rate was more rapid during exercise than in the tilt position. At rest, the peripheral systolic time was uniformly prolonged beyond that of the central pulse, brachial-artery values being closest to those of the central pulse and femoral-artery values deviating the most.

Comment

In 1890 Hürtlhe noted a higher systolic and wider pulse pressure in the crural than in the carotid artery of the dog. Frank considered the increase in pulse pressure and the absolute increase in systolic pressure of the peripheral over the central pulse as its most prominent features and this led him to doubt the hypothesis of simple transmission of the pulse wave as in an endless elastic tube. These amplitude changes have been noted in man by Hamilton and co-workers and by Schnabel and co-workers. These investigators found that, although there was an increase of systolic pressure peripherally, the diastolic and mean pressures remained relatively constant. Wood and co-workers demonstrated that in addition to the increase in systolic pressure peripherally there was a small but significant drop in diastolic and mean pressures. These latter findings have been confirmed by our present studies.

The hypotheses of the transformation of the central to the peripheral pulse have been summarized by Hamilton and Dow. Our findings are best explained by the hypothesis that the increase in amplitude and change of contour in passage from the central to the peripheral pulse is due to the summation of the incident
wave with the reflected wave from the periphery. Resonance effects in the peripheral arterial systems probably also play a role, especially under conditions of cardiovascular stress such as the Valsalva maneuver. The increase in central pulse pressure amplification to the radial artery in the tilt above that seen at rest and exercise (table 4) may at least partially be attributed to compensatory vasoconstriction in this condition. The peripheral resistance would be increased and there would be an increase of positive wave reflection. The smaller drop in mean pressure in this condition as compared to rest and exercise would be compatible with reduced flow secondary to the vasoconstriction.

The decrease in amplification of central pulse pressure at the femoral artery during exercise was marked as compared to the rest and tilt conditions (table 4). As the exercise consisted of pedalling with the opposite leg, a decrease in peripheral resistance would be expected secondary to vasodilatation in the vascular bed supplied by the femoral arteries; a decrease in positive wave reflection would result and therefore a decrease in amplification of pulse pressure. It is probable that the character of the systolic ejection from the left ventricle also affects the degree of peripheral amplification of the pulse pressure. In severe aortic stenosis, for instance, the increase in systolic pressure peripherally is small or an actual decrease occurs, while in contrast the amplification of the pressure pulse peripherally is exaggerated in patients with severe aortic insufficiency (unpublished).

**Summary and Conclusions**

Central (aortic or subclavian), brachial, radial, and femoral pressure pulses were recorded simultaneously by means of intraarterial needles and catheters in 14 studies on 12 healthy subjects during conditions of rest, exercise and 70 degree head-up tilt.

The average central arterial pressure was 126 (113-146) mm Hg systolic and 81 (71 to 90) diastolic. Preoscillations and anacrotic oscillations were evident. As this pulse wave was transmitted peripherally, striking changes in contour occurred, along with a small progressive decrease in diastolic and mean pressure and a larger progressive increase in systolic pressure. Peripheral systolic pressure at rest uniformly exceeded the central systolic pressure generated by the same heartbeat; brachial was 109 per cent, radial 112 per cent and femoral 110 per cent of central systolic pressure. The average radial pulse pressure was 146, 146 and 165 per cent of central pulse pressure during rest, exercise and tilt respectively, while radial mean pressures were 94, 93 and 98 per cent of central mean pressures respectively. Femoral pulse amplitude was similar to that of the radial except during exercise of the opposite leg when femoral pulse pressure was only 114 per cent of central pulse pressure.

The velocity of the pulse wave was increased toward the periphery, the buildup time was shortened while the systolic time was prolonged. The contour of the pulse wave was uniformly strikingly different in the brachial-radial and femoral-dorsalis pedis system. A double systolic wave developed in the pressure pulse during transmission peripherally from the subclavian artery. The primary systolic wave increased in amplitude, the secondary systolic wave usually decreased and the dicrotic dip was exaggerated during transmission down the arm. In contrast, the pressure pulse at the femoral artery consisted of a single systolic wave followed by a poorly defined or absent dicrotic dip. These time relations and changes in contour, in conjunction with corresponding pressure alterations, best describe the changes that the pulse wave undergoes in transit to the periphery.

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