The Changes in the Intra-Arterial Pressure during Immersion of the Hand in Ice-Cold Water

By John O. Godden, M.D., Grace M. Roth, Ph.D. and Edgar A. Hines, Jr., M.D.

With the Technical Assistance of Jerry F. Schlegel, B.S.

The response of the intra-arterial pressure to the cold immersion stimulus was studied in 42 healthy young adults, continuous direct (arterial-pressure) recording being used. The average systolic elevation was 22.6 mm. Hg and the average diastolic elevation was 16.3 mm. Hg. The difference between direct and indirect methods of measuring blood pressure was studied in 351 simultaneous determinations in 35 of these young adults. The direct systolic pressure averaged 9.7 mm. Hg higher and the diastolic pressure was 7.3 mm. Hg lower than the indirect measurement.

The cold pressor test of Hines and Brown has been used widely during the past 22 years in the study of essential hypertension and the toxemias of pregnancy. Up to the present, exact knowledge of the nature and significance of the cold pressor response has been limited by the intermittent measurements possible with the sphygmomanometer. However, now that continuous direct recording of arterial pressure is established as an accurate and reliable laboratory procedure, a new tool is available for the study of the cold pressor test.

The response of the intra-arterial pressure to the cold immersion stimulus (4 C. for 60 seconds) was studied in 42 healthy young adults, continuous direct arterial pressure recording being used. The cold pressor test of Hines and Brown was applied repeatedly at short intervals, and the direct record was examined with regard to (1) maximal elevation of pressure, (2) time required to reach the maximal pressure and (3) time needed to return to one half the maximal pressure (the last figure was taken as a measure of the recovery time). The difference between the direct and indirect methods of measuring blood pressure was studied in 351 simultaneous determinations in 35 of these young adults.

HISTORY OF THE COLD PRESSOR TEST

In 1932, Hines and Brown described an icewater immersion test (the cold pressor test) designed to measure individual vascular reactivity. Many methods of stimulation, including electric shocks, loud noise, bright lights and the inflicting of pain, had been tried previously. However, none of these stimuli gave consistent results when repeated in the same individual. Hines, working with the late Dr. G. F. Brown, had observed that a patient with cold sensitivity responded with a marked elevation of blood pressure when an extremity was immersed in ice water. The development and application of this cold pressor test are described in the following papers. The test has been used since by others chiefly in the investigation of essential hypertension and toxemia of pregnancy.

By 1940, Hines had applied this test approximately 5,000 times in 1,856 persons, of whom 1,015 had a usually normal blood pressure and 841 had essential hypertension. In the entire group with a usually normal blood pressure, the mean increase was 16.2 mm. Hg for the systolic pressure, and 13.2 mm. for the diastolic. The group with a usually normal blood pressure was divided into hyporeactors and hyperreactors on the basis of a rise less than, or more than, 20 mm. of mercury in systolic and 15 mm. in diastolic blood pressure. Approximately 85 per cent of subjects with usually normal blood pressure fell in the group of hyporeactors. In 1951, Hines revised his limits of normal vascular reactivity to define normoreactors as those having a diastolic elevation between 10 and 20 mm. Hg.

The cold pressor test rests on certain assumptions regarding the physiology of the cardiovascular

From the Mayo Clinic and Mayo Foundation, Rochester, Minn. The Mayo Foundation is a part of the Graduate School of the University of Minnesota. Abridgment of the thesis submitted by Dr. Godden to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science in Medicine.
system. Some of these assumptions are as follows:

1. The individual response to the cold stimulation, applied exactly as described by Hines, is constant to a degree suitable for use as a clinical test (±10 mm. Hg).

2. Rapid elevations of blood pressure, unassociated with cardiac acceleration or increased cardiac output, are brought about by vasoconstriction which produces a sudden increase in peripheral resistance.

3. This test is a measure of vasoconstrictor response. The diastolic elevation to the stimulus is a more reliable index of vasoconstriction than the systolic increase.

4. The cold pressor test is an index of vascular (vasoconstrictor) reactivity.

There is, to our knowledge, no literature on the response of the intra-arterial pressure to cold stimulation either in health or in disease. Hines and Brown reported, from their studies using indirect measurement of blood pressure, that a sustained increase in the cold pressor response is seen only in persons with essential hypertension.

This study investigates the response of intra-arterial blood pressure in 42 adult human subjects to a standard cold stimulus (the cold pressor test). A continuous record was made of the beat-to-beat changes in arterial blood pressure in 42 healthy young adults. The primary purpose of this project was to study the intra-arterial pressure response to cold immersion with a newer and more accurate technic. This approach studies the total cardiovascular response as expressed in peripheral arterial pressure to a powerful stimulus.

METHODS AND PROCEDURE IN THIS STUDY

The group of 42 healthy young adults who cooperated in this project was unselected in any way, except that any person having a history or physical findings suggestive of cardiovascular or renal disease was excluded from the project. The women were young student nurses, all subject to pretraining and, thereafter, annual physical examinations. The men were either student nurses, hospital orderlies or graduate physicians. The population of the project is weighted in favor of young female subjects, the majority having “low normal” blood pressures. No selection was made on the basis of the response of the individual to the cold pressor test.

Casual indirect blood-pressure readings obtained from the young adults used in this project were reviewed in respect to the new standards of normal blood pressure proposed by Master and associates. Almost 300 indirect measurements were made and in only two isolated estimations were these limits exceeded at either the systolic or diastolic levels.

Two female subjects had indirect blood-pressure determinations on one occasion of 130/90 and 120/86 respectively. The limit of normal pressure for this age group of Master and associates was 130/85.

Intra-arterial pressure was conducted through the radial needle up a saline-filled polyethylene tube to the strain gauge (fig. 1). This instrument converts the mechanical thrust of blood pressure into electric energy, which moves the stylus of the recorder. A wash bottle filled with heparinized saline solution, joined in parallel with the strain gauge, allows the radial needle to be flushed out by adjusting the three-way stopcock. The flushing of the radial needle with saline solution has no discernible effect on the intra-arterial pressure, except that it obliterates the direct record for three to five pressure pulses. An aneroid manometer was used to keep the pressure in the system above arterial pressure at all times. An ice bucket, thermometer and blood-pressure cuff needed for the cold pressor test completed the equipment.

A Sanborn polyviso multichannel recorder was used, inscribing simultaneously (1) the electrocardiogram, (2) respiratory excursions and (3) direct arterial pressure. Two Statham strain-gauge manometers of different sensitivities were needed for respiratory (10.4 pounds per square inch) and circulatory (0 to 15 pounds per square inch) pressures. (Both can be seen in fig. 2; the pulmonary strain gage lying beside the pillow is concealed by the wash bottle in fig. 1.) The method of using this equipment has been described by Wood, Lambert and Burchell. The same equipment was used and the same technic was followed throughout the project unless otherwise noted.

The Sanborn recorder was allowed to “warm up” for 20 to 30 minutes. Each stylus had been tested for sensitivity and adjusted if necessary. The stylus recording arterial pressure was calibrated against an aneroid manometer* through the range expected in the individual subject, that is, from the lowest diastolic pressure at rest to the highest systolic

* This instrument has been checked repeatedly with a mercury manometer, which is the permanent standard in the cardiac-catheterization laboratory of this institution.
pressure obtained during cold stimulation. This calibration was inscribed stepwise in increments of 20 mm. Hg at the beginning and end of each record. It was later used to derive a scale card for the measurement of the individual pulse wave in millimeters of mercury.

Each radial puncture produced a continuous record of the intra-arterial pressure during the performance of three or more cold pressor tests which were preceded, separated and followed by 15-minute rest periods. The record contained the individual’s response, by blood-pressure alteration, to three or more severe stress situations (fig. 3). The records were later studied with regard to (1) basal pressure, (2) maximal pressure obtained as a result of stimulation, (3) time elapsed from stimulation to maximal elevation in pressure and (4) time from stimulation to one-half maximal pressure after cessation of stimulus.

A continuous electrocardiographic tracing was made throughout the direct arterial-pressure recording, standard lead II being used. A short record of the standard leads I, II and III and the three unipolar limb leads aVR, aVL and aVF was included at the end of the tracing. The individual QRS deflections were discernible even at slow paper speeds.

A continuous record of the respiratory cycle was made, an oxygen mask connected to a pressure manometer being used. A large rounded wave of good amplitude was recorded in response to the pressure changes at the oral end of the airway. This record gave reliable evidence of the quality of the subject’s steady state. The details of the technique for recording the individual direct pressure tracing were largely empirical during the early stages of this project. There were two limiting factors, the duration of the steady state under the conditions required for direct recording, and the time required for the subject to recover from the effects of a powerful vasomotor stimulus. A trial, reported below, was made during which 10 young adults were subjected to five cold pressor tests, at 15-minute intervals. The results of this exercise enabled us to adopt two postulates: (1) The subject could tolerate the radial needle and the discomfort of repeated cold immersions for at least one hour. (2) There was no significant difference between repeated cold pressor tests.

A standard one-hour procedure was subsequently adopted in which three cold pressor tests were carried out at 15-minute intervals. The individual cold pressor tests in our project were recorded at either 5 mm. per second or 25 mm. per second paper speeds. The same speed was used for the basal period (20 seconds before immersion), for the minute during immersion and for a period of 30 seconds after withdrawal of the stimulus. All resting periods were recorded at a speed of 1 mm. per second, which allowed continuity to be maintained with a minimal expenditure of record paper.

The shape of the pressure pulse was frequently altered by reflected waves which appeared on the descending limb of the pulse wave, either distorting the dicrotic notch or separate from it. These reflected waves, which are agreed to be evidence of increased peripheral vasoconstriction, were followed at rapid paper speeds until they disappeared from the record. They persisted, in some cases, for several minutes, passing away as the blood pressure declined toward basal levels.

INTERPRETATION OF THE DIRECT TRACINGS

The response of the channel of the Sanborn unit which recorded arterial pressure was calibrated, as previously described, through the expected maximal range from the lowest diastolic to the highest systolic pressure before and after each individual procedure. A scale card was constructed from these calibrations which measured the amplitude of the pressure pulses directly in millimeters of mercury (the white rectangle at the left margin of fig. 3). The definition of certain terms used in reporting the results of this study follows:

(1) The basal pressure, systolic and diastolic, is defined as the average of all appropriate pressure pulses in the 20-second period just before immersion. The basal pressure was taken in the period immediately before the application of the cold stimulus in order to cancel out, as far as possible, any rise in blood pressure due to other causes.

(2) The maximal pressure given is the value, in millimeters of mercury, of the pulse wave of greatest amplitude occurring during or after
cold immersion. Pressure pulses rising abruptly above the general level of their contemporary pulse waves and those occurring immediately after release of the blood-pressure cuff were not used. The common artifacts in the tracings were due to the brief obliteration of the pulse wave during simultaneous use of the blood-pressure cuff and, in one case, to the occasional occurrence of cardiac extrasystoles.

(3) One-half maximal pressure is the value, in millimeters of mercury, of the first pressure pulse, occurring after maximal elevation has been attained, having an amplitude midway between that of the basal and maximal pulse waves. This value can be determined by simple arithmetic without scanning the postwithdrawal segment of the direct record. However, the time of occurrence of this pressure was considered to be important in this project.

(4) The time to maximal pressure and the time to half-maximal pressure are the intervals measured in seconds from the immersion of the hand in ice water to the occurrence of the appropriate pulse wave.

There are three groups of normal subjects. These groups are cumulative, that is, group I forms part of group II and group III takes in all normal subjects. Group I: 10 subject each having five consecutive tests; Group II: 36 subjects each with three tests and Group III: 42 subjects with a total of 136 tests.

Initially, 10 healthy young adults were subjected to five consecutive cold pressor tests at 15-minute intervals to study the consistency of response in repeated tests. Then, an additional 26 young adults had three consecutive cold pressor tests at the same interval. These individuals and those in group I make up the 36 subjects in group II. These two groups are reported together and compared in various ways later in the paper. Finally, the data from 136 cold pressor tests in 42 young adults were combined and examined as 136 individual tests.

A comparison of direct and indirect blood-pressure determinations was made in 35 of the 42 healthy young adults taking part in this project.

A preliminary study was made to determine the time needed for return to resting blood pressure between repeated cold pressor tests.

A group of 10 healthy young adults was studied, during the design of the project, to determine the consistency of the individual response to repeated immersion stimuli. It was important to learn if the subject retained his ability to respond maximally when the
stimuli were applied at short (15-minute) intervals, inasmuch as no information was available regarding the time needed for recovery after the cold pressor test.

Ten young adults, six men ranging from 20 to 26 years of age (average 22 years) and four women, all 20 years of age, were each subjected to five cold pressor tests at 15-minute intervals. The mean elevations in arterial pressure of each series of tests (test 1 in 10 subjects, and so forth) were examined statistically for the significance of differences between consecutive tests. These differences of means, 10 systolic and 10 diastolic pairs in their various combinations, when compared, showed that the differences of two systolic pairs, tests 1 and 2 and tests 1 and 3, had borderline significance but, in the small sample examined, there was no significant difference in the diastolic responses. Tables 1 and 2 contain the results of this preliminary study. The data for five consecutive cold pressor tests in 10 young adults are in the upper row of figures for tests 1, 2, 3, and 4 and are the only figures presented for tests 4 and 5. The figures pertaining to the larger group of 36 subjects can be disregarded at this time. The basal pressure of this group becomes elevated after test 1, the resting pressure rising 5.1 mm. Hg at the systolic level and 3.8 mm. at the diastolic level. This figure recedes toward the initial level in test 3 but in tests 4 and 5 begins to rise again, perhaps owing to fatigue and the discomfort of the procedure.

The maximal systolic pressures obtained after cold immersion show elevations ranging from 23.0 to 30.2 mm. Hg. These elevations are partly due to the contribution of two subjects who had marked pressor responses of 58 and 49 mm. of mercury (average of four tests). The diastolic responses are similar to the systolic except that all pressures are higher in test 5 than in the preceding tests.

The mean rise in arterial pressure following cold immersion shows a marked decrease in pressor response after the first test, especially at the systolic level. The successive mean systolic elevations above the basal level beginning with test 2 are respectively 7.2 mm., 4.4 mm., 4.9 mm. and 2.0 mm. less than the systolic elevation in test 1. The diastolic elevations in tests 2, 3, and 4 are 2.6 mm., 0 mm. and 0.4 mm. less than the diastolic elevation in test 1, while the diastolic elevation in test 5 is 1.0 mm. greater than that in test 1. The decrease is due, in large part, to the elevation in basal pressure which occurs when the subject is introduced to the painful experience of cold immersion.

The results of this preliminary study make certain conclusions possible (see below). However, such conclusions rest on several assumptions: (1) The pretest basal pressure is very close to the patient's resting blood pressure. (2) The subject will respond maximally to each immersion stimulus. (3) No other potent vasomotor stimuli are operating during the procedure.

Conclusions from the Preliminary Study

(1) A consistent response is obtained when the cold immersion stimulus is applied repeatedly to the same individual.

(2) There is a noticeable elevation in the basal pressure after the individual has been subjected to the first cold pressor test. This is
less marked at the diastolic level than at the systolic level.

(3) This elevation in the basal pressure after the first cold immersion accounts, in large part at least, for the reduction in pressor response of subsequent tests.

(4) There is no evidence in this data that "cold adaptation," as described by Wolf and Hardy, takes place in the human subject when the time of immersion is limited to 1 minute.

(5) There is probably a limit in each individual to the maintenance of the steady state.

**GROUP II: MODIFIED STUDY OF REPEATED TESTS ON 36 YOUNG ADULTS**

This group consists of the 10 subjects in the first group and 26 other subjects. There were nine men, aged 20 to 32 years (average 23.7 years) and 27 women, aged 18 to 25 years (average 20.2 years). The findings in these healthy young adults are presented, along with those in group I, in tables 1 and 2. The smaller number of repeated tests (three consecutive tests at 15-minute intervals) in the larger group seems to give a more accurate estimation of the true pressor response in young adults. The diastolic pressor response in test 1 in each group was 18.2 (group I) and 16.5 mm. Hg (group II).

**RESULTS OF THE STUDY OF THE ENTIRE GROUP OF HEALTHY YOUNG ADULTS**

The response of the intra-arterial pressure of 42 healthy young adults to cold stimulation is presented in table 3. This group was made up of nine men, aged 20 to 32 years (average 23.7 years), and 33 women, aged 18 to 32 years (average 20.6 years).

The data provided by these young adults are presented as single tests in each individual, also as 136 tests in 42 subjects. In clinical medicine the cold immersion stimulus is used as a single test (the cold pressor test) to estimate vascular reactivity. The response of these 42 young adults to single tests is reported because such treatment is directly comparable with clinical results. Multiple tests in this group were examined to accumulate data on the response of healthy subjects to the cold immersion stimulus. The basal pressures obtained from the 42 subjects in the two groups of tests show close resemblance. The mean systolic level in the first tests is 2.1 mm. Hg lower and at the diastolic level 0.5 mm. lower than the values in the multiple tests. The range of blood pressures from which these samples were drawn is quite wide, but only one subject was at the upper limit of the range of the normal population by the standards of Master and associates. This female subject, referred to above, had an indirect blood-pressure determination of 130/90, while the limit of Master and associates for this group is 130/85.

The maximal pressures are shown for the two groups immediately below the basal pressures. The data for 42 and 136 tests show very close correlation. The mean elevation in pressure ("rise") recorded in these subjects after cold immersion varies in a wide range from 4 to 58 mm. Hg at the systolic level and from 4 to 42 mm. at the diastolic level. The mean rise in these individuals, either in single or in multiple tests, is of considerable magnitude, that is, systolic elevations of 24.4 and 22.6 mm. Hg and diastolic increases of 18.5 and 16.3 mm. respectively. The standard error of the mean and the standard deviation of the

**Table 3. Response of Intra-arterial Pressure to a Cold Stimulus in 42 Young Adults**

<table>
<thead>
<tr>
<th>Pressures, mm. of mercury</th>
<th>Tests</th>
<th>Systolic</th>
<th>Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean*</td>
<td>S.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal</td>
<td>42</td>
<td>113.4 ± 1.43</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>115.5 ± 0.86</td>
<td>10.03</td>
</tr>
<tr>
<td>Maximal</td>
<td>42</td>
<td>137.8 ± 2.16</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>138.0 ± 1.05</td>
<td>12.25</td>
</tr>
<tr>
<td>Rise in pressure</td>
<td>42</td>
<td>24.4 ± 1.57</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>22.6 ± 0.46</td>
<td>5.34</td>
</tr>
</tbody>
</table>

* The figure after the ± sign is the standard error of the mean.
larger group of tests are definitely smaller than those of the 42 tests, suggesting that the larger group is approaching the true mean.

The time, in seconds after immersion, taken to reach the maximal elevation in pressure is shown in the upper half of table 4. The time taken to pass through the maximal elevation and reach a value of one-half maximal pressure is shown in the lower half of the table. This one-half maximal time is measured in seconds from the moment of immersion of the hand in ice water. The results in the two groups of tests are very similar. The range of response times and the significance of these results will be discussed with the graphs of distribution.

### Table 4. — Time Required for Maximal and Half-maximal Response to a Cold Stimulus in 42 Young Adults

<table>
<thead>
<tr>
<th>Tests</th>
<th>Systolic</th>
<th></th>
<th></th>
<th>Diastolic</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean*</td>
<td>S.D.</td>
<td>Range</td>
<td>Mean*</td>
<td>S.D.</td>
<td>Range</td>
</tr>
<tr>
<td>Time† to maximal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pressure</td>
<td>42</td>
<td>55.9 ± 2.44</td>
<td>15.8</td>
<td>4-72</td>
<td>56.4 ± 2.18</td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>56.0 ± 1.27</td>
<td>14.7</td>
<td>4-88</td>
<td>54.4 ± 1.09</td>
<td>12.7</td>
</tr>
<tr>
<td>Time† to ½-maximal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pressure</td>
<td>42</td>
<td>68.8 ± 2.95</td>
<td>19.1</td>
<td>7-104</td>
<td>66.0 ± 2.38</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>67.4 ± 1.29</td>
<td>14.95</td>
<td>7-104</td>
<td>67.7 ± 1.17</td>
<td>13.6</td>
</tr>
</tbody>
</table>

* The figure after the ± sign is the standard error of the mean.
† Time in seconds after immersion.

### Mean Elevation of Arterial Pressure Following Cold Immersion

The distribution of the elevation of intra-arterial pressure in 136 cold pressor tests on 42 young adults is shown in figure 4. The average pressor responses for the entire 136 tests are indicated by vertical arrows at the top of the graph. Sixty-two per cent of the systolic elevations lie between 15 mm. and 30 mm. Hg, 86 per cent of the group had responses less than 30 mm. and 98 per cent were less than 40 mm. for the diastolic response, 78 per cent of the elevations lie between 10 mm. and 30 mm. Hg, and 98 per cent of the elevations were less than 30 mm. Hg. These data were also plotted as the logarithm of the values for pressure elevation but the contour of the graph did not change significantly. This logarithmic graph is not shown here.

The pressor responses, both systolic and diastolic, group themselves around a major peak at about 13 mm. Hg and a minor peak at the level of 26 mm. Hg. The data of cold pressor responses on many thousands of young subjects might show that, in respect to the cold pressor test, there are two or more “kinds” of individuals.

### Time from Immersion to Maximal Elevation of Pressure

The time, in seconds, from immersion to maximal elevation of pressure in 136 cold pressor tests on these 42 young adults is shown in figure 5. The times to maximum, at the...
systolic level, are concentrated so that 80 per cent of the group lie between 50 and 70 seconds after immersion. The entire group had the highest elevation before 80 seconds, that is, within 20 seconds after stimulation was withdrawn. The times to diastolic maximum are almost identically grouped; 79 per cent of the responses, at this level, fall between 50 and 70 seconds after immersion. One hundred per cent of the diastolic rises are completed within 80 seconds of the application of stimulation.

The principal feature of figure 5 is the promptness of the pressor response and the narrow limits of the reaction times in these individuals. The mean response times are shown at the top of the graph by vertical arrows.

**TIME FROM IMMERSION TO ONE-HALF MAXIMAL PRESSURE**

The time, in seconds, from immersion to the occurrence of one half the maximal pressure in 42 young adults is shown in figure 6. The half-maximal time is a measure of the time required, by the vasomotor system, for recovery from the cold immersion stimulus. The time of return to basal pressure is very difficult to determine with precision because the blood pressure is continually changing. The half-maximal time marks the moment when much of the pressor effect has passed off and the arterial pressure has declined midway to its resting level.

The principal feature in figure 6 is, as in figure 5, the promptness with which the vasomotor system readjusts to the pressor stimulus. The pressor response is a definite but a transient phenomenon. At the systolic level 72 per cent of the group had passed from maximal pressure to half-maximal pressure within 20 seconds, that is, between 60 and 80 seconds. Within the same short period, 81 per cent of the diastolic pressures declined from the greatest elevation midway to the basal level. Within 50 seconds of the cessation of the stimulus, the systolic pressures of the entire group had reached the half-maximal point and 10 seconds earlier, all the diastolic pressures had completed this part of the recovery.

The mean systolic and diastolic half-maximal times are shown by vertical arrows at the top of the graph.

**ELECTROCARDIOGRAPHIC CHANGES DURING COLD IMMERSION**

Electrocardiographic changes were limited to transient conduction disturbances (sinus arrhythmia) and, in one case, occasional nodal extrasystoles. These changes were associated with distortion of the concurrent pulse wave but did not cause a persistent change in the amplitude of the pressure pulse.

**COMPARISON OF THE SIMULTANEOUS DIRECT-INDIRECT BLOOD-PRESSURE MEASUREMENTS**

In this study, the direct arterial pressure was recorded from the right radial artery and the indirect arterial pressure was estimated over the right brachial artery. The error introduced by this arrangement can be estimated by examining the comparative values for direct brachial and radial arterial pressures as the percentage of central (arterial) pressure according to Kroeker,\(^{16}\) given in table 5. These are average values from 12 normal subjects, the central pressure being measured in the aorta near the arch or in the left subclavian artery near its origin from the aorta. Therefore,

**Table 5.—Direct Brachial and Radial Arterial Pressures as Percentage of Central Arterial Pressure (From Kroeker)**

<table>
<thead>
<tr>
<th></th>
<th>Systolic</th>
<th>Diastolic</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial</td>
<td>109</td>
<td>96</td>
<td>98</td>
</tr>
<tr>
<td>Radial</td>
<td>112</td>
<td>93</td>
<td>94</td>
</tr>
</tbody>
</table>
for the purpose of the direct-indirect comparison discussed below, direct brachial and radial pressures are almost identical.

Simultaneous direct and indirect blood-pressure determinations were compared in 35 of the 42 young adults taking part in this study.

This comparison was made possible by a compromise between the demands of the two technics. When the recording needle lies in the right radial artery and the blood-pressure cuff is inflated on the right upper arm, both needle and cuff cannot record the arterial pressure at the same time. The period of immersion in ice water was divided in the following manner: the technician, who carried out all the indirect pressure determinations, was instructed to make her estimations in the period between 20 seconds and 50 seconds after immersion. The direct maximal pressure was then identified in the period after the 50-second interval.

The recommendations of the Committee on Standardization of Blood Pressure Readings of the American Heart Association were followed in these indirect pressure determinations. The technician had used the muffling of sounds as the indication of diastolic blood pressure for many years in the peripheral vascular laboratory of this institution. This criterion was used during this project. During the resting or basal period of the direct arterial-pressure recordings 289 paired estimations were made and 62 direct-indirect comparisons were obtained at the maximal elevation of pressure, following cold immersion. Table 6 shows the difference between these simultaneous determinations but gives no direct information about the original pressures which were compared to devise these data.

The reference point in these comparisons is always the direct arterial-pressure estimation, that is, +9.7 means that the direct pressure was 9.7 mm. Hg higher than the simultaneous indirect determination. When the range of pressures from which the mean pressure was derived is quoted, –18 means that the lowest direct estimation was 18 mm. Hg less than its simultaneous indirect estimation, and +34 means that the direct pressure was 34 mm. of mercury greater than the indirect pressure. The first part of table 6 shows that when simultaneous pressure determinations are made with these two methods, the direct systolic pressure will be, on the average, 9.7 mm. Hg higher than the indirect systolic estimation.

At the other level, the direct diastolic pressure will be 7.3 mm. Hg less than the indirect diastolic figure. The direct arterial-pulse pressure is, on the average, 17 mm. of mercury greater than the indirect measure of the systolic-diastolic difference.

The difference between the two methods is definitely increased when the maximal pressures after cold stimulation are compared. Dameshek and Loman found that the indirect error increases as the pulse pressure increases. In a smaller group of paired estimations at the level of maximal pressor response, the direct systolic pressure was, on the average, 16 mm. Hg higher than the indirect result. The direct diastolic estimation was 11 mm. Hg lower than the diastolic pressure recorded with the cuff at the same instant. The comparisons at the moment of maximal pressor response are not absolutely simultaneous: the operator using the cuff was directed to make her measurements between 20 and 50 seconds of the minute after immersion. The direct maximal pressor response was measured after 50 seconds.

A comparison of the difference between direct and indirect blood-pressure determinations in these 35 healthy young adults with the data from a similar simultaneous examination made by Roberts and associates on 30 elderly

Table 6.—Difference Between Simultaneous Direct and Indirect Blood-Pressure Determinations in 35 Young Adults

<table>
<thead>
<tr>
<th>Pressure, mm. of mercury</th>
<th>Paired estimations</th>
<th>Systolic Mean*</th>
<th>S.D.</th>
<th>Range</th>
<th>Diastolic Mean*</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal ..................</td>
<td>289</td>
<td>+9.7 ± 0.61</td>
<td>10.4</td>
<td>–18 to 34</td>
<td>–7.28 ± 0.48</td>
<td>8.2</td>
<td>–31 to 20</td>
</tr>
<tr>
<td>Maximal ................</td>
<td>62</td>
<td>+16.2 ± 1.3</td>
<td>10.2</td>
<td>–7 to 40</td>
<td>–11.1 ± 1.08</td>
<td>8.6</td>
<td>–25 to 9</td>
</tr>
</tbody>
</table>

* The figure after the ± sign is the standard error of the mean.
male patients in a veterans’ hospital is presented in Table 7. As far as can be determined, Roberts and associates used the same recording equipment and a technic similar to that used in this project except that they recorded the direct arterial pressure at the brachial artery. The data on the comparison of radial and brachial arterial pressure, given by Kroeger and referred to in Table 5, lead us to believe that the brachial recording of Roberts and associates and the present radial recording can be compared without serious error. The upper row of Table 7 displays the results of simultaneous blood-pressure determinations in 30 elderly patients. The lower row of figures repeats the results of the comparison made in this present study. The plus and minus values have the same significance in this table as in Table 6.

**Summary**

The response of the intra-arterial pressure to the cold immersion stimulus was studied in 42 healthy young adults, continuous direct (arterial-pressure) recording being used. The difference between direct and indirect methods of measuring blood pressure was studied in 351 simultaneous determinations in 35 of these young adults. The results of this study are as follows:

1. These subjects responded to a cold stimulus with a prompt, and usually marked, elevation of arterial pressure. The response is described as “prompt” because 94 per cent of the subjects reached maximal systolic elevation between 40 and 70 seconds after immersion and 96 per cent of the group reached maximal diastolic elevation in this 30-second period. The elevation was marked in most cases except for two subjects who had responses of less than 5 mm. Hg. The average systolic elevation was 22.6 mm. and the average diastolic elevation was 16.3 mm. Hg.

2. These subjects responded in a consistent manner to repeated cold pressor tests carried out at short (15-minute) intervals. When 10 subjects underwent five consecutive tests, there was a borderline significance in the differences between tests 1 and 2 and also between tests 1 and 3, at the systolic level. There was no significant difference in the responses to the five consecutive tests at the diastolic level.

3. The recovery from the effects of the cold immersion stimulus is rapid, as assessed by measure of the time from application of the stimulus to return of the arterial pressure to the half-maximal pressure.

4. The differences between simultaneous direct and indirect blood-pressure determinations in 35 young adults were as follows: the direct basal systolic pressure averaged 9.7 mm. Hg higher than the indirect systolic pressure; the direct basal diastolic reading was lower, on the average, by 7.3 mm. Hg. The difference between the two methods was increased when the comparison was made at the moment of maximal pressor response. At this time, the direct systolic pressure was, on the average, 16.2 mm. Hg higher than the indirect systolic pressure. At the diastolic level the direct pressure determination was 11.1 mm. Hg lower than the indirect measure. Thus, the pulse pressure determined directly was 27.3 mm. Hg wider than the indirect pulse pressure.

**Sumario in Interlingua**

Le responsa del pression intra-arterial al stimuli de immersion algide esseva studiate in 42 juvenes normal. Le metodo usate esseva le continue directe registrazion del pression arterial. Le elevation systolic median esseva 22,6 mm Hg; le elevation diastolic

---

Table 7.—Difference Between Simultaneous Direct and Indirect Blood-Pressure Determinations in 30 Elderly Patients and 35 Young Adults

<table>
<thead>
<tr>
<th></th>
<th>Authors</th>
<th>Persons</th>
<th>Paired readings</th>
<th>Systolic</th>
<th>Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean*</td>
<td>S.D.</td>
</tr>
<tr>
<td>Brachial</td>
<td>Roberts</td>
<td>30</td>
<td>30</td>
<td>+3.2 ± 2.8</td>
<td>15.4</td>
</tr>
<tr>
<td>Radial</td>
<td>This paper</td>
<td>35</td>
<td>289</td>
<td>+9.7 ± 0.61</td>
<td>10.4</td>
</tr>
</tbody>
</table>

* The figure after the ± sign is the standard error of the mean.
median eseva 16.3 mm Hg. Le differentias inter le directe e le indirecte methodo de mesurar le pression sanguinee eseva studiate in 35 del mesme juvane adults. Esseva executate 351 determinaciones simultaneen con le duo methodos. Le valor median del pression systolic secundo le methodo directe eseva 9.7 mm Hg plus alte que secundo le methodo indirecte. Le valor median del pression diastolic secundo le methodo directe eseva 7.3 mm Hg plus basse que secundo le methodo indirecte.

REFERENCES
The Changes in the Intra-Arterial Pressure during Immersion of the Hand in Ice-Cold Water

JOHN O. GODDEN, GRACE M. ROTH, EDGAR A. HINES, JR. and Jerry F. Schlegel

Circulation. 1955;12:963-973
doi: 10.1161/01.CIR.12.6.963

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1955 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/12/6/963