

## THE EFFECT OF SOME HYDROTHERAPEUTIC PROCEDURES ON THE BLOOD-FLOW IN THE ARM \*

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### INTRODUCTION

It is generally agreed that therapeutic baths exercise a profound effect on the circulation of the blood. The exact changes, however, are not fully understood and this lack of knowledge is due to a number of causes. In the first place it is not easy to transfer the results of animal experiments to man because the skin vessels in the latter are more active and the temperature regulation more exact. In the second place alterations in the distribution of blood in the body, seemingly the most marked circulatory effect of baths, are not readily studied in man. The blood-pressure gives no definite information as to this distribution because the dilatation of one set of vessels may be neutralized by the constriction of another set, and the changes in pulse tracings are extremely difficult to interpret.<sup>1</sup> On the other hand, the plethysmograph which records the volume changes in an extremity and presumably the variations in the contained blood has added greatly to our scientific knowledge of the action of hot and cold water on the distribution of blood. Its use, however, is limited because it is necessary to keep the individuals extremely quiet during manipulations.

Considering the difficulties encountered in trying to obtain exact data, it is not surprising that frequent contradictions occur in the hydrotherapeutic literature concerning the effects of baths on the peripheral circulation. For this reason it seemed important to approach the subject from a new direction. We have therefore studied the effect of some representative hydrotherapeutic procedures on the blood flow in the arm, using a method recently described.<sup>2</sup> Many of our results correspond with those already obtained by the plethysmograph, but they are of interest because they are expressed in terms of blood flow. As has been indicated, the use of the plethysmograph is limited, as the individual must remain quiet during the observations and because the instrument cannot be taken off and replaced during an experiment. For this reason the reaction after a cold bath and the effect of exercise and friction cannot be studied by the plethysmograph, and our ideas concerning these have been deduced

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largely from such evidence as the sensations of the patient and the color and warmth of the skin. The method which we have used permitted a removal and a replacement of the instrument on the arm so that comparative records before and after treatments could be obtained. We have therefore been able to study the effect of exercise, friction and the reaction after cold baths.

#### EFFECTS OF LOCAL PROCEDURES

The application of hot or cold water to the arm is one of the simplest hydrotherapeutic procedures, and the effect of such applications on the local circulation has been studied by various methods. U. Mosso,<sup>3</sup> Sarah Amitin<sup>4</sup> and others have shown that in general the arm shrinks under the influence of cold and swells under the influence of heat. A. Mosso<sup>5</sup> has shown that the size of the volume pulse is diminished by local cold and increased by local heat, and Balli's<sup>6</sup> tachograms show similar changes. Lommel<sup>7</sup> has shown that the rate of propagation of the arterial wave is accelerated by local applications of cold. From these and other observations it has become generally accepted that the arteries and other blood-vessels in the extremities contract under the influence of local cold and dilate under the influence of local heat, and it has been assumed that the local blood-flow is lessened in the former condition and accelerated in the latter. Friedel Pick<sup>8</sup> has proved this for the legs of dogs by direct measurements of the venous outflow.

In order to study the effect of thermic stimuli on the local blood-flow, we have modified our method by partially filling the plethysmograph with water. The temperature of this latter could be varied by passing hot or cold water through an encased coil of block tin. Records of the blood-flow made at frequent intervals were compared with the temperatures of the water surrounding the arm.

It is well known that the volume of the arm often fluctuates considerably in the ordinary plethysmograph, and we found similar fluctuations in the rates of flow. Inaccuracies of the method undoubtedly accounted for many of the minor fluctuations. Others, however, were probably due to psychic or other nervous influences which, as Weber<sup>9</sup> and others have shown, exert a powerful influence on the caliber of the peripheral vessels. These nervous variations could usually be distinguished from those produced by thermic influences on account of their transient and variable character. They were most apt to be encountered when the blood-flow approximated the normal rate, and tended to diminish when the water surrounding the arm was either hot or cold. When both arms were studied, fluctuations were frequently encountered in the arm which was placed in an air plethysmograph and was not directly subjected to strong thermic stimuli. These observations are comparable to the experiments of Friedel Pick, who showed that when the leg of a dog was exposed to

hot or cold water the usual vasomotor effects of cutting or stimulating the sciatic nerve did not occur. The influence of strong thermic stimuli transcended the nervous influences.

The general qualitative effect of thermic influences on the local blood-flow in our experiments was very constant. Whenever definite results were obtained, heat always accelerated the local flow and cold always diminished it. A typical chart of this class of experiments is shown in Figure 1. It will be seen that the original rate of 3.7 c.c. of blood-flow per 100 c.c. of arm substance per minute when the arm was surrounded by water of 24 C. was gradually reduced by the cooling of the water until a minimum rate of 1.1 c.c. was obtained when the water temperature had fallen to 14.5 C. In all of our experiments a similar fall occurred but we were unable to use very low temperatures on account of the pain in the arm caused by the cold. On this account, perhaps, we obtained no increased flows at very low temperatures such as would correspond to the

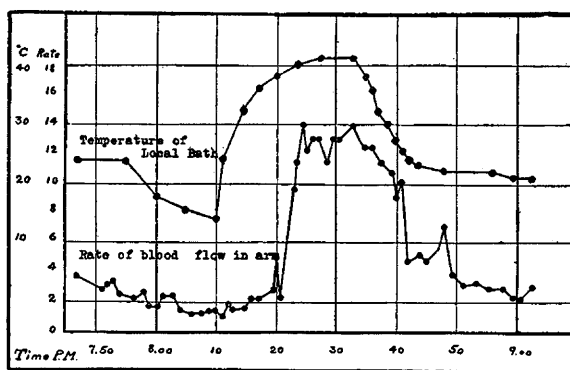


Fig. 1.—The effect on the local blood-flow of varying the temperature of the water surrounding the arm. Note that for corresponding temperatures the flow is more rapid when the temperature is falling than when it is rising.

swelling of the arm described by U. Mosso or to the relative increase of heat elimination described by Robinson and Stiles.<sup>10</sup> On this account also, perhaps, when the arm was again heated to a neutral temperature we obtained no excessive increases in the rate of flow such as one might expect from the changes in volume described by U. Mosso, or the changes in volume pulse pictured by A. Mosso. As a rule in our experiments the rate of flow did not immediately increase when the temperature surrounding the arm was raised, but remained relatively slower than it had been for corresponding temperatures when the temperature of the water bath was falling. Thus we obtained no records which could be interpreted as showing a "paralysis of the vessels" from cold.

High temperatures invariably produced a most marked acceleration of the rate of flow. This developed more suddenly in Figure 1 than in

most of our experiments; but there was nearly always a rapid increase in the rate of flow at about the time that the temperature of the water passed 35 to 38 C. The increases from the original rates to the maxima were always very marked, much more so than those which Friedel Pick obtained in dogs. The following figures give the rates per minute per 100 c.c. of arm substance before and after the application of heat: 3.7 c.c. to 14 c.c., 4 c.c. to 29 c.c., 6 c.c. to 22 c.c., 5 c.c. to 26 c.c., 3 c.c. to 26 c.c., 4 c.c. to 22 c.c., 6 c.c. to 45 c.c.

When the temperature of the water bath was again reduced after reaching temperatures of 42 C. to 50 C., the rate of flow always fell; but this fall never occurred promptly and for a given temperature of the arm bath the rate of flow was invariably faster than when the temperature was rising (Figs. 1, 2 and 3). Similar results published by U. Mosso for the volume changes in the arm were interpreted as indicating a vascular paralysis, a subject which will be discussed later.

Several causes contribute to produce the fluctuations in the rate of blood flow which follow the local applications of hot or cold water. It is difficult, however, to estimate the exact part played by each. Theoretically one may consider: (1) the direct action of heat or cold on the blood-vessels or their local nervous connections; (2) reflexes excited by thermic stimuli and acting on local vessels; (3) reflexes excited by thermic stimuli and acting on the vessels of the body in general; and (4) the effect of cooling or warming the blood. The separation of the first two of these or the local effects, from the last two or the general effects, can be accomplished by a simultaneous study of the two arms when only one of these is subjected to external changes in temperature.

Studies of this character have yielded very contradictory results. U. Mosso describes a single experiment in which the arm exposed to hot water became swollen while the opposite arm, exposed to an indifferent temperature, shrank. Sarah Amitin, in similar experiments, found that while the arm in hot water became swollen the opposite arm did not change volume. She found, however, that when one arm was exposed to cold water both shrank. Friedel Pick obtained unilateral effects in studying the action of thermic stimuli on the blood flow in the legs of dogs. On the other hand, many observers in recent years, notably O. Müller,<sup>11</sup> have emphasized the fact that the vessels in the two arms tend to act in unison when one is subjected to hot or cold applications. We have carried out several sets of experiments in which the rates of flow in the two arms were compared while one was exposed to hot or cold water and the other was in an air plethysmograph, and we are inclined to believe that the contradictory reports published by others may be explained by variations in the room temperature.

The first set of these experiments were made during the spring months of 1910, in a fairly warm room. During the application of heat to the arm, the body as a whole became warm and the individual perspired freely. Figure 2 shows the results obtained in one of the three experiments performed at this time, all with uniform results. It will be seen that the application of heat to the right arm caused an increased blood-flow in the left arm. In contrast with the right, however, this increase in the left took place somewhat later, did not reach the same high point, and the rate decreased more promptly when the right arm was cooled to

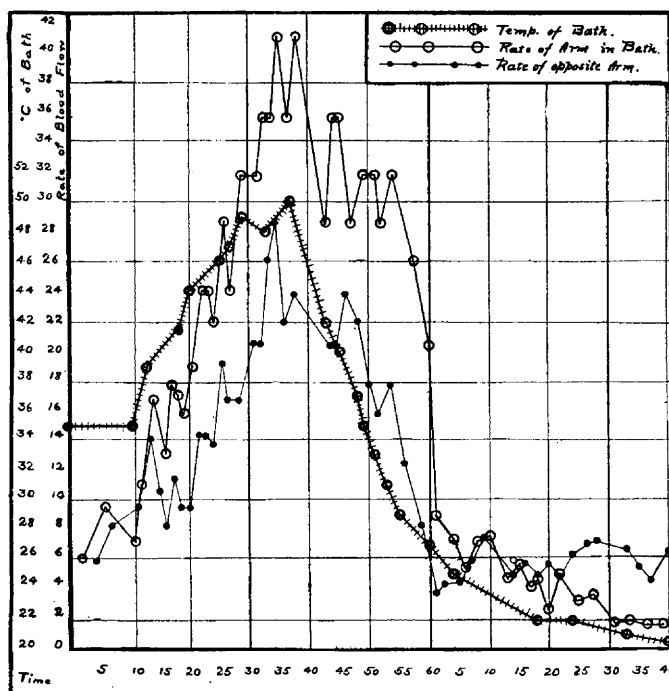


Fig. 2.—The effect of varying the temperature of the water surrounding one arm on the blood-flow in this and in the opposite arm, the room being warm. The right arm was exposed to the varying temperatures, the left was in an air plethysmograph. Note that when heat was applied the blood-flow in the latter rose later, did not reach the same high point, and fell more promptly. Also that when cold was applied the flow in the right arm fell below that in the left.

a neutral temperature. When the water was still further cooled (below 25 C.), the rate in the arm exposed to the cold diminished, while it remained approximately normal in the other. The marked discrepancy between these results and those of U. Mosso and of Sarah Amitin led us to repeat this experiment in a cold room, taking care that the individual should remain slightly chilly throughout. In Figure 3 it will be seen that under these conditions the arm directly exposed to the changing

temperature showed the customary changes in blood-flow while the opposite arm showed throughout a slow rate of flow, the maximum increase not being over twice the original rate. When the water in the plethysmograph was cooled, both arms showed an extremely slow and approximately equal blood-flow. The different results in these two experiments show clearly that the room temperature exercises an important influence on the distant vascular reaction when hot or cold water is applied to a limited part of the periphery. They also show that the local effects of such applications are largely independent of the general effects. O. Müller<sup>11</sup> also noticed that the temperature of the room disturbed the general effects, but in a somewhat different manner from what we have described. He states that when the temperature of the room was considerably below 20 C., the distant effects of cold were lessened and conversely when the temperature of the room exceeded 20 degrees the distant effects of local heat were lessened.

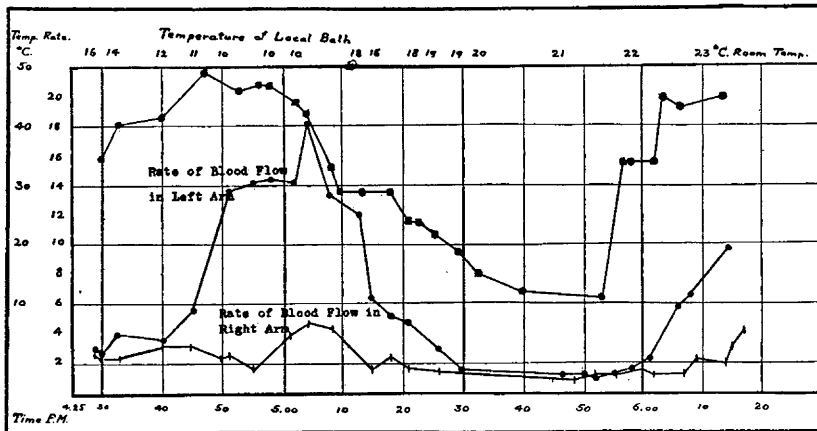


Fig. 3.—The effect of varying the temperature of the water surrounding one arm on the blood-flow in this and in the opposite arm, the room being chilly. The upper curve represents the temperature of the local bath, the middle the blood-flow in the arm to which the water of varying temperatures was applied, and the lower the blood-flow in the arm contained in the air plethysmograph. Note that heat increased the flow in the left arm very markedly while it did not greatly affect that in the right arm. At low temperatures both arms showed a very slow rate of blood-flow.

To demonstrate this more clearly a final experiment was performed, during which the room temperature and the temperature of the water about the arm were varied independently. During the first part of this experiment the room was kept at a constant temperature of 22 C. to 24 C., while the temperature of the water bath surrounding the left arm was raised from 32 C. to 41 C. The blood-flow in the left arm increased from an average of 5 c.c. per 100 c.c. of arm substance per minute, to

15 c.c., while the blood-flow in the right arm varied but little from the original rate of 4 c.c. During the second part of the experiment the temperature of the water bath was maintained at 42 C., while the temperature of the room was reduced from 24 C. to 12 C. In this period the blood-flow in the left arm fluctuated in the neighborhood of 16 c.c. while the blood-flow in the right arm fell from the neighborhood of 4 c.c. to about 2 c.c. During the third period the temperature of the water surrounding the left arm continued to be about 42 C. while the temperature of the room was raised from 12 C. to 30 C. In this period the rate of blood-flow in both arms increased. That of the left rose from 17 c.c. to 27 c.c.; that of the right from 2 c.c. to 7 c.c. During the fourth period the room was kept warm and the temperature of the water surrounding the left arm was reduced from 42 C. to 14 C. The rate of blood-flow in the left arm fell from 27 c.c. to 2 c.c., while that in the right arm fell from 7 c.c. to 4 c.c. In the final period the temperature of the room was again reduced to the chilling point and the rates in both arms fell still further, approximating each other at a little over 1 c.c. In this experiment the blood-flows in the arm exposed to the changing temperatures of the water followed these changes rather closely and were but moderately affected by the room temperature. The blood-flows in the opposite arm, on the other hand, depended chiefly on the room temperatures but was moderately affected by the changes in the temperature of the water surrounding the first arm.

Our experiments demonstrate that thermic stimuli produce both local and general effects on the peripheral blood-vessels. The former are shown by the facts that (1) when heat is applied the blood-flow is always relatively faster in the arm to which it is applied; (2) when the individual is kept cool or chilly, the rate in the opposite arm may not be accelerated; and (3) when cold is applied the blood-flow in the affected arm is often less than in the opposite arm. The effect of local applications on the blood-vessels of the opposite arm is indicated by the fact that the blood-flow in the latter frequently undergoes changes similar to, though usually not so great as, those which occur in the arm directly treated.

The factors causing the distant effects of heat and cold will be discussed later. Concerning their local action we have two possibilities. The first of these would attribute these effects to reflexes originating from the heated or cooled skin and acting on the local vessels. While it is possible that such reflexes occur, they do not seem to be necessary, for Friedel Pick observed characteristic changes in the blood-flow following thermic applications to the legs of dogs even after the sciatic nerves were cut. This seemed to indicate that thermic influences may act directly on the local nervous or vascular apparatus. Similar results have been obtained by others.<sup>1</sup>

When the arm is heated excessively, signs may appear which indicate a loss of contractile power on the part of the vessels. U. Mosso assumed the existence of such a "vascular paralysis" as the result of heating the arm, and based his assumption partly on the observation that after a thorough heating the vessels do not contract promptly when cold is applied. While our observations on the blood-flow confirm his, we are inclined to give them a different interpretation. The temperature to which the tissues are exposed is not the same as the temperature of the surrounding water bath. When the tissues are thoroughly heated the local blood-flow is markedly increased; the deep layers of the skin are relatively protected from the cold water bath, and one would not expect a sudden contraction following its use. Occasionally, however, the skin remains red for hours, even days, after exposures to very hot water. Furthermore, in several of our experiments the curves obtained after very hot water were peculiar in that only a small amount of blood could enter the arm at a uniform rate. To our minds this indicated that the vascular reservoir was diminished, and taken in conjunction with the fact that the rate was very fast and the arm red, it seemed to us probable that the vessels were dilated to their utmost and did not empty sufficiently between determinations to allow the reception of much more blood. This effect persisted for some time after the rate began to fall as a result of cold applications but ultimately completely disappeared. In such a case, and also where the skin remains abnormally red, one might speak of a "vascular paralysis."

#### EFFECT OF GENERAL PROCEDURES

General hydrotherapeutic treatments are usually initiated by a hot procedure, such as an electric cabinet bath, and are usually terminated by a cold procedure, such as a cold shower. In some cases cold procedures alone are used. Exercise, friction, the mechanical action of douches, and the temperature of the room are important accessories. In the present study we have aimed to determine the effect of general hot and cold procedures on the circulation in the arm. We have also tried to outline the part played by some of the above named accessories. Finally, mouth temperatures have been taken during many of the experiments for the purpose of comparing these with the peripheral blood-flows and with the ability of the individuals to react. Prolonged cold and medicated baths such as are used in the treatment of fever and of heart disease were not studied.

#### SUMMARY OF EXPERIMENTS

A number of experiments were carried out, the results of which are shown below in the form of tables. A general discussion follows. Many details of the experiments have necessarily been omitted from the tables



such as, for example, the fluctuations in blood-flow caused by nervous influences or by errors in the method employed. Some idea as to the extent of these fluctuations may be obtained from Figures 1 to 4. When the fluctuations were very marked the figures given in the tables have been starred. When more or less continuous changes in rates occurred, especially after hot or cold procedures, the changes have been indicated by a dash connecting the earlier with the later rates. All temperatures have been expressed in the centigrade scale, and the blood-flows have been expressed in terms of the number of centimeters of blood entering 100 c.c. of arm substance per minute. The plethysmograph always included the hand, forearm and lower arm.

In the first set of experiments, represented in Table 1, the individuals were placed at rest in a bath tub, and the original rates were taken while the individuals were covered by a light blanket. Hot water (41 C. to 45 C.) was then run into the tub. This usually covered the lower extremities, the abdomen and parts of the chest and of one arm, leaving the arm in the plethysmograph outside of the water. The subjects were left in the hot water until a profuse perspiration occurred. After this the water was allowed to run out of the tub and a spray with tap water under high pressure and at a temperature of about 15 C. was given without moving the individual or the apparatus. The rates of flow through the arm were taken at frequent intervals throughout the experiments. In some instances the shower was repeated once or twice, but the results of these secondary showers are not charted in this table.

TABLE 1.—HOT TUB BATHS FOLLOWED BY COLD SPRAYS

Name	Room Temp.	Original Rate	Average Maximum Rate in Bath	Rate when Water Ran Out	After Spray	Maximum Mouth Temp. in Bath
Hew. ....	25 C.	3.3*	14.4	14.4	14.5	38.5 C.
Hew. ....	23 C.	...	20.0	16.0	14.	38.4 C.
Meg. ....	25½ C.	2.2	12.4	7.1	3.2	37.9 C.
Alex. ....	....	4.3*	20.0	13.0	5.4	37.9 C.
Sti. ....	24 C.	2.7	18.0	14.	4.3	....
Gan. ....	22 C.	2.2	22.0	10.	2.5	....
Sch. ....	21 C.	2.0	13.0	6.5	4.0	38.3 C.
Cha. ....	21 C.	2.0	14.	2.2	2.0	38.1 C.
Lot. ....	23 C.	2.0	11.0	10.1	3.6	....

In the experiments shown in Table 2 the same procedures were used except that in place of hot water the individual was surrounded by numerous blankets which were heated by an enclosed set of incandescent lamps. The direct rays from the lights did not reach the skin. The "after spray" rates were taken as in the previous set of experiments. The individual then took an ordinary cold shower, dried himself and dressed. The rates after these procedures are given in the last column.

TABLE 2.—HOT AIR BATHS FOLLOWED BY COLD SPRAYS

Name	Room Temp.	Original Rates	Average Maximum Rates	Rates when Blankets were Removed	After Spray	Highest Mouth Temp.	After Ordinary Shower
.....	.....	.....	.....	.....	.....	.....	.....
Hew. ....	21 C.	6.5	10.0	6.0	5.0	37.2 C.	7.4
Hew. ....	26 C.	5.7	12.	10.0	4.3	37.5 C.	4.2

In Table 3 the individuals were placed at rest in a tub, and the shower was given without any preliminary heating.

TABLE 3.—COLD SPRAYS WITHOUT HOT PROCEDURES

Name	Room Temp.	Rates Before Shower	Rates After Shower	Rates After Dressing
.....	.....	.....	.....	.....
Lot. ....	23. C.	1.4	1.3	1.8
Lil. ....	23.5 C.	2.6	1.3	2.5

Two objections may be raised to the results obtained in these experiments. In the first place the arms from which the observations were taken were kept continuously in the air plethysmograph and did not come in contact with the hot or cold water. In the second place important accessories to a therapeutic treatment were absent, such as the exercise taken during or after the bath and the local friction from douches and from rubbing with hands or towels.

Table 4 shows the results obtained during observations made on patients of the psychopathic hospital who were taking baths for therapeutic purposes. We were permitted to make these observations through the courtesy of Dr. A. M. Barrett. In these cases rates were taken before the electric cabinet bath, after the electric cabinet bath, and finally after cold procedures which consisted of gradually cooled showers and douches.

TABLE 4.—ELECTRIC CABINET BATHS FOLLOWED BY COLD SHOWERS

Name	Average Room Temperature	Original Rates	After Coming Out of E. C. B.	After Cold Procedures	Highest Mouth Temperature
.....	.....	.....	.....	.....	.....
Smi. ....	26 C.	6.7	10.0	8.5	37.5 C.
Schu. ....	24 C.	4.7	11.5	4.5	37.7 C.
Wood ....	24 C.	5.3	10.0-6	5.2	37.3 C.
Per. ....	24 C.	5.0*	11.0	5.2*	37.5 C.

In Table 5 are recorded the effect of cold showers as ordinarily taken by vigorous young adults. The rates were taken before undressing, after undressing and finally directly after drying, the individual being lightly covered with a blanket.

TABLE 5.—COLD SHOWERS

Name	Room Temperature	Dressed	Undressed	After Shower	Mouth Temperatures Before	After
.....	.....	.....	.....	.....	.....	.....
Hew. ....	25 C.	6.2	6.7	4.4-5.8	37.0 C.	36.6 C.
War. ....	25 C.	2.0	2.4	5.9	36.7 C.	37.2 C.
Hoy. ....	25 C.	2.6	3.8*	4.1	37.0 C.	36.9 C.

In these last two sets of observations the apparatus was taken off and applied several times. The cold procedures were accompanied by considerable exercise and were followed by a vigorous rubbing with a towel. While it was impossible to obtain as many records in these cases, and while the immediate effects of procedures could not be followed, yet they represent more accurately the changes which occur in practical bath treatments.

#### EFFECT OF HOT PROCEDURES

As hot procedures, the full tub bath, the hot air bath and the electric cabinet bath were used and these were continued until the individuals perspired profusely. During these applications of heat the mouth temperatures invariably rose. During the hot air and the electric cabinet baths, the mouth temperatures rose to at least 37.2 C., and usually to 37.5 C. or 37.7 C. In the full tub baths the individuals were partly covered with hot water (41 C. to 43 C.), and the body temperatures usually rose above 37.8 C. and frequently above 38 C. During these hot procedures the rate of blood-flow through the arm invariably increased, never being below 10 c.c. per 100 c.c. of arm substance per minute, and often exceeding 20 c.c. These rates were from two to ten times the original rates, but this ratio seemed to depend more on the original than on the final rate. The flow increased, even though the arm itself was not directly exposed to high temperatures. While in general the acceleration of flow was greater when the mouth temperature was high, there seemed to be no strict parallelism between the two.

When the hot procedures were over and the individuals were exposed to ordinary room temperatures, a fall occurred in the rate of blood-flow through the arm, usually reaching 70 per cent. or less of the highest previous rate. In one patient (Table 1 Cha.), who was quite unaccustomed to baths, the rate rose during the hot tub bath from 2 c.c. per 100 c.c. of arm substance per minute to 14 c.c., but it fell to the original rate when the hot water was let out of the tub. The body temperature at this time was 37.8 C., and we regarded this abrupt fall as pathological. The results obtained on the patients of the psychopathic hospital (Table 4) showed rather less than the customary accelerations of blood-flow after the electric cabinet bath. Two causes contributed to produce this result. One was the initial warm temperature of the room, which gave these patients relatively rapid rates before entering the cabinet. The other was the fact that our apparatus was reapplied after the patients had come out of the cabinet, and that during the elapsed time the rates probably fell below what they had been in the cabinet.

#### EFFECT OF COLD PROCEDURES

The effect of simple cold procedures following the hot procedures was quite uniform in that they always caused a fall in the rate of flow through the arm. The extent of this fall varied greatly. In some the cold reduced

the flow to less than the original rate while in others the reduction was much less marked, and the flow was left considerably above the original, though usually below that produced by heat. In a general way, when no exercise was taken and no friction was given, the rate of blood-flow was more apt to remain above the original rate if the body temperature had been much elevated by the preceding heat. In such cases the individuals usually took the cold showers with ease and were left warm and exhilarated, reactions being obtained without exercise or friction.

When primary cold procedures were given without exercise and without friction, or when repeated cold procedures without these were given after hot ones, the rate of flow through the arm was reduced by each shower. This result was obtained both when the arm studied had been directly exposed to the cold water and when it had been protected by being enclosed in the plethysmograph.

Attempts were made repeatedly to obtain records during the cold showers but the results were rather unsatisfactory, partly on account of involuntary movements of the individual and partly because it was difficult to protect the plethysmograph from the cold spray which caused the enclosed air to shrink. We frequently gained the impression, however, that the flow during the shower was somewhat slower than it was a few minutes later.

#### EFFECT OF VARIATIONS IN BODY TEMPERATURE

Warm procedures invariably raised the mouth temperatures to some extent. In our experiments this was most marked in those taking hot water tub baths which usually raised the temperature to 37.9 C. or over. When hot air or electric cabinet baths were used, the rises in temperature were less marked but the mouth records often exceeded 37.5 C. The more marked effect of hot water baths is due in part to the high specific heat of water but still more to the fact that they prevented evaporation from the portions of the body immersed in water so that the individuals lost this method of maintaining their normal temperatures. During cold procedures the body temperatures were not reduced below the normal in a large number of therapeutic treatments studied, but when cold procedures were given without following the customary rules of hydrotherapy, it frequently happened that the mouth temperatures fell below 36.7 C.

To what extent do these variations in the body temperature influence the blood-flow in the arm and the various phenomena accompanying hydrotherapeutic treatments? The effect of the body temperature is naturally a general one and not dependent on the point at which the thermic application is made. It must, therefore, be distinguished from the local effect of hot or cold water which usually exceeds the distant effects. It would seem from experimental evidence that such distant effects of hot procedures may be produced either by reflexes excited by

stimulation of the thermic sense organs in the skin<sup>12, 13</sup> or by changes in the temperature of the carotid blood which supplies the brain.<sup>14</sup> The relative importance of these factors in producing the circulatory changes of man during the therapeutic use of water has not been carefully studied by scientific methods, though recent writers<sup>11</sup> have usually assumed that distant effects are caused by reflexes arising from the cutaneous thermic sense organs and acting on the peripheral vessels by way of the vasomotor center.

Several facts indicate that the body temperature is a factor which cannot be neglected in this connection. The ordinary measures used in therapeutic institutes for hydrotherapy emphasize the importance of preventing heat losses from the body. The rooms are kept unusually

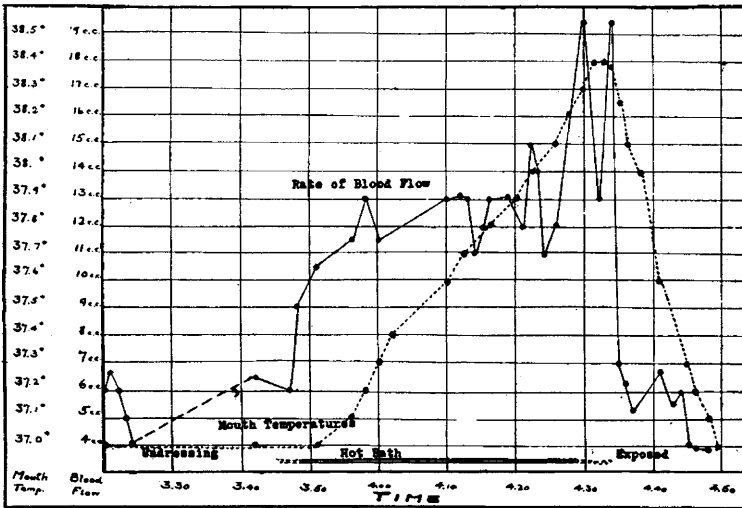


Fig. 4.—The relation between the mouth temperature and the blood-flow in the arm during a hot tub bath. Note that the rate rose at the beginning of the bath before the mouth temperature showed a change; also that the rate fell when the water ran out while the mouth temperature was still above 38 C.

warm, the cold procedures are short, and individuals not accustomed to baths are given preliminary hot procedures. In our experience when the body temperature is reduced, cold procedures are apt to leave the individuals chilly and with a slow peripheral rate of flow. After hot water baths, on the other hand, where the body temperature is considerably elevated, cold procedures are borne unusually well, even though the room is cold. The one exception to this rule which we observed (Cha., Table 1) was regarded as a pathological chilling on exposure to a cool room after a warm procedure.

In order to study more accurately the relation between the effect of thermic stimuli and the effect of body temperatures, two experiments

were performed in which an effort was made to distinguish these factors. The experiments were performed in a cool room (18.5 C.); the individuals were given hot tub baths, and the body temperatures were raised to about 38.4 C. The water was then run out of the tub and the individuals left exposed to the cool air of the room until the mouth temperatures fell to normal. A series of readings were made of the mouth temperatures and of the rates of flow through the arm. Essentially the same results were found in both experiments but the more striking of the two are shown in Figure 4.

In Figure 4 it will be seen that the original rate of about 6 c.c. fell under the influence of a cool room and partial exposure to 4 c.c. The individual then undressed and was covered with a light blanket, the rate at the end of this being 6.5 c.c. The tub was filled with water of a temperature of 41.7 C., and the rate of blood-flow rose almost immediately to above 10 c.c. This change occurred before any rise in the mouth temperature was recorded. As the body temperature rose, the rate of blood-flow took a slightly higher level and finally with the body temperature of 38 C. the blood-flow reached a high mark of 19 c.c. In the other experiment this secondary rise of blood-flow did not occur. When the water was run out of the tub and the individual was exposed to the cold air of the room, the rate of blood-flow fell almost immediately to the neighborhood of 6 c.c., although at this time the mouth temperature remained above 38 C. A marked fall in blood-flow did not occur until the temperature reached 37.3 C., when the rate fell somewhat below the original rate.

In these experiments we have a clear demonstration that the rate of blood-flow in the arm which was kept continuously in the air plethysmograph varied independently of the body temperature. The rate increased promptly when the body was covered with hot water and before the body temperature was raised and it fell promptly when the water was let out, although the body temperature remained high. We believe, however, that the experiments also showed a definite effect of the elevation of body temperature. From our experience, naked exposures to a room temperature of 18.5 C. should send down the rate much more than what was found seven minutes after the hot bath.<sup>15</sup> It seems probable that the elevated body temperature prevented a still further fall of blood-flow. In contrast to these observations we have noted on several occasions that when the body temperature was slightly subnormal, exposure to a cool room almost immediately reduced the flow to the neighborhood of 1 c.c., and the individual became very chilly. We believe that these experiments indicate that while the external temperature exercises a more powerful effect on the peripheral blood-flow than does the body temperature, the effect of the latter should not be neglected. In practical hydrotherapy the

slight elevations of temperature caused by the hot procedures, and the avoidance of excessive heat losses tend to prevent the excessive constriction of the vessels with chilling which are apt to follow exposure to cold air or cold water if the body temperature is normal or subnormal.

#### THE EFFECT OF EXERCISE AND FRICTION

We have already stated that in our experiments, cold procedures without exercise or friction were invariably accompanied by a fall in the rate of flow through the periphery (Tables 1, 2 and 3). This occurred even though the spray did not last long and even though the subjects felt exhilarated and not chilly. Similar results were obtained when the arm was taken out of the plethysmograph and directly exposed to the spray.

In Table 5, however, it will be seen that in two of three individuals a primary cold bath was followed by an acceleration in the peripheral rate of flow. Similar results were obtained on several occasions at the end of long tub experiments when the individual took a final cold shower with exercise and rubbing. (See for example the first experiment in Table 2.) It would appear from a comparison of our results that when an acceleration of flow occurs after primary cold procedures, it is due to the exercise and friction with which these are accompanied. This was especially noticeable in Table 5, War., who showed the most marked increase of flow, was unaccustomed to showers, took a very short one, and exercised vigorously. The difference in our results may have been due in part to the fact that where the arm was kept continuously in the plethysmograph careful drying was not attempted and the rate was held down by the wet condition of the skin. Under any circumstances, it is certain that primary cold procedures never accelerate the rate of flow through the arm to the same extent as do hot procedures. In some cases a moderate acceleration is obtained; in others the rate is not much changed. When, however, the cold is given without friction, exercise and drying, the rate of flow invariably falls as a result of the procedure.

#### THE REACTION

The reaction after cold procedures plays an extremely important part in practical hydrotherapy. The patient is said to react well when he feels exhilarated and warm and when the skin becomes pink. The absence of these—but especially the sense of chilliness—constitutes a failure to react. It is not always easy to define a reaction. This is especially true when the individual feels exhilarated and warm immediately after the cold procedure but becomes chilly on the least exposure or spontaneously within the next half hour or so. The conditions which are used to favor reaction are preliminary hot treatments, warm rooms, short cold procedures, and the use of exercise and friction.

In our experience, decided failures to react are always associated with a slow peripheral rate of flow. This was seen especially in those experiments where successive sprays were given to individuals who had been heated by a hot tub bath. In these cases the chilliness indicative of the failure to react always occurred when the blood-flow in the arm had become unusually slow. On the other hand, even a fairly typical reaction was not necessarily accompanied by a fast rate of blood-flow through the arm. In some cases (Table 2) the rate fell after a cold spray and yet the individuals gave the appearance and had the sensations of fair reactions. In such cases the red color of the skin must have been a purely local phenomenon and not associated with a dilatation of the deeper vessels. Usually the best reactions were seen when the rate of blood-flow did not sink much below the original rate, and quite frequently it was moderately elevated during the reaction. Our experiments seem to dispose finally of the old views of Winternitz which have been subjected to a destructive criticism by Matthes,<sup>1</sup> concerning the effect of cold and heat on the blood-flow in the arm. Winternitz believed that heat caused a "passive" dilatation of the vessels with slowing of the blood-current. Numerous physiological experiments as well as our observations on man have shown that heat markedly accelerates the rate of blood-flow in an extremity. The effect of cold, however, is more complicated. It is well recognized that under ordinary conditions cold contracts the blood-vessels and lessens the blood-flow. When intense cold is applied for some time, as in the case of an ice-bag, it causes a redness due to a dilatation of the local capillaries. We are unable to say whether this is accompanied by an increased flow or not. Furthermore, in the reaction after cold procedures it has been assumed that there is dilatation of the blood-vessels, and Winternitz went so far as to state that this "active" dilatation, in contradistinction to the dilatation caused by heat, is accompanied by an increased flow. Our experiments indicate that while the blood-flow may be increased during reaction this is never very marked and it is never increased to the same extent as it is during hot procedures.

On the other hand, we frequently obtained the impression that a secondary dilatation of the blood-vessels may occur following cold procedures independently of the immediate effect of exercise and friction, though it was difficult to be certain that this dilatation did not result merely from the cessation of the cold stimulus. In one case (Table 5, Hew.), however, we had an unusually clear association between the glow of a reaction and an increase in the rate of blood-flow. In this experiment the original rates of flow varied from 5.5 c.c. to 7.2 c.c. Immediately after undressing a rate of 6.7 c.c. was obtained, but a cold draft from the room in which the cold shower was running caused a momentary chilliness with reduction of the rate to 4 c.c. An ordinary cold shower was then



taken, following which the individual dried himself, returned to the tub, and was loosely covered with a dry blanket. The rates of flow taken immediately after were 4.8 c.c. and 4.2 c.c., and at this time he still felt a little cold from the water. After the second determination a feeling of warmth was experienced, and with this the rate of flow increased to 5.6 c.c. and 6 c.c. In this case the feeling of warmth and the increased rates were not due to the immediate effect of exercise or friction because they occurred when the individual was at rest. This glow with normal or somewhat increased rate of flow may occur even though the body temperature is subnormal. We were able to demonstrate this repeatedly when cold showers with exercise and friction were taken at the end of long tub exposures. While it is possible thus to raise the rate by the ordinary cold shower in vigorous individuals with subnormal temperatures, and while at the time these individuals often feel momentarily exhilarated and warm, it was noticed repeatedly that they were at the same time very sensitive to chilling influences and that a slight draft would cause a chilling sensation with a marked slowing of the rate. It was also noticed that when these individuals remained quiet in a room of ordinary temperature the glow was apt to be followed by chillness. It seemed to us therefore that while a momentary reaction may be produced when the body temperature is subnormal, such a reaction is apt to be fleeting and followed by chillness on slight exposure.

Our experiments support the general practice in hydrotherapeutic rooms of preventing such heat losses that the body temperature is lowered. Even when this is done, some individuals (Table 1, Cha.) may chill when exposed to cold air or cold water. The ideal conditions for a reaction after cold are attained when exercise and friction are used, the room is warm, and the body temperature is not allowed to fall below the normal.

#### CONCLUSIONS

1. When hot water is applied to the arm, the local rate may be increased from four to eight times, and when cold is applied the local rate may fall to one-half or one-fourth of the original.

2. These variations are often associated with similar, though less-marked changes in the blood-flow in the opposite arm. The latter is also influenced by the room temperature and the chillness or warmth of the individual.

3. A diminution of the contractile power of the vessels may occur after exposure to excessively hot water.

4. General hot procedures cause a marked acceleration in the blood-flow through the arm, and general cold procedures without exercise, friction or drying decrease the blood-flow in the arm.

5. When exercise, friction and drying are given with cold procedures, the slowing may be more or less neutralized and the rate may even be raised somewhat above the original.

6. Acceleration of blood-flow in an arm not directly exposed to the hot procedure is due in the main to reflexes excited by thermic stimulation of the cutaneous sense organs. The rise of body temperature, however, tends to prevent an excessive contraction of the peripheral vessels when the individual is exposed to cold.

7. If the body temperature is subnormal an immediate reaction may follow cold procedures which are accompanied by friction and exercise, but the individual is liable to become chilly later.

8. Reactions are usually, but not necessarily, accompanied by normal or moderately increased rates of flow.

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