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Effects of Some Physical Therapies on Blood Flow

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Plethysmograph and thermal measurements have yielded much valuable information concerning the effects of various physical therapies on blood flow. These methods for estimating the volume blood flow have an advantage in that they can safely be applied to the human subject but are unsuitable, for the most part, for conditions which require continuous measurements of slow and rapid changes in blood flow in absolute rather than in relative units. In previous reports accounts have been given of the construction and use of an electromagnetic blood flow meter for measuring the volume blood flow through the vessels of laboratory animals.[1] This method, although it possesses a high degree of accuracy, unfortunately cannot be employed in studies on the human subject or in repeated studies on animals.

This study is concerned with the effects of several physical therapies on the volume blood flow through the hind extremities of adult dogs. The physical therapies employed were massage, passive stretching, electrical stimulation and the application of hot foments. Measurements of blood flow were made in the femoral artery of both anesthetized and unanesthetized dogs. The studies were made on normal, denervated and spastic limbs.

Experimental Method

The method for measuring the volume of blood flow through the femoral artery has been described previously.[1-2-3] In the experiments on unanesthetized animals, local infiltration of two per cent procaine hydrochloride was employed to prevent pain resulting from the exposure and cannulation of the artery. Some experiments were carried out under pentobarbital sodium anesthesia. Heparin was used as the anticoagulant in all experiments. Usually a period of from fifteen to thirty minutes was allowed to elapse after cannulation of a vessel for the establishment of steady states of blood flow in the control period.

Denervation was accomplished by severing both the sciatic and femoral nerves seven to fourteen days prior to study. Spasticity in the muscles was produced by a local injection of a standardized dose of tetanus toxin into the popliteal space of one limb.

Massage of the deep effleurage and petrissage types was applied to the hind limb of the dog by a physical therapist. A definite rhythm was established and the movements, primarily in a centripetal direction, followed the

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* This work was aided by a grant from The National Foundation for Infantile Paralysis, Inc.
* Read at the Twenty-Ninth Annual Session of the American Congress of Physical Medicine, Denver, September 6, 1951.

1. Richardson, A. W.; Randall, J. E., and Hines, H. M.: A Newly Developed Electromagnetic Flow Meter, J. Lab. and Clin. Med. 34:1706 (Dec.) 1949.
2. Feucht, B. L.; Richardson, A. W., and Hines, H. M.: Effect of Hot Foments on Volume of Blood Flow in Extremities of Dogs, Arch. Phys. Med. 30:687 (Nov.) 1949.
3. Richardson, A. W.; Imig, C. J.; Feucht, B. L., and Hines, H. M.: The Relationship Between Deep Tissue Temperature and Blood Flow During Electromagnetic Irradiation, Arch. Phys. Med. 31:19 (Jan.) 1950.

pattern of the large muscle group in the leg. The massage was applied for a five-minute period. Volume blood flow was recorded before, during and for at least five minutes following the massage.

Three series of experiments were designed to demonstrate the effect of passive stretching upon the volume blood flow in the normal, spastic and denervated hind limbs of unanesthetized dogs. The stretching consisted of taking the gastrocnemius muscle through its full range of motion by flexing the foot upon the leg with the knee fixed in the extended position. Six excursions through the range of motion were used for each experiment. The range of motion was usually severely restricted in the animals with spastic limbs. The volume flow was recorded before, during and following the stretching period until the flow returned to or approached control level. The flows were analyzed at one-half-minute intervals and the average flow for the duration of the change was calculated.

The effect of electrical stimulation of muscle upon volume blood flow through the femoral artery was studied in dogs under anesthesia. Electrical stimuli were applied to the musculature of the leg in one of several ways. The first method used was the application of faradic current to the sciatic nerve using shielded electrodes. A second group had faradic current applied directly to the muscle through needle electrodes. A clinical stimulator furnished damped sinusoidal current oscillating at a rate of forty times per minute. The active muscle electrode was placed in the vicinity of the motor point of the gastrocnemius muscle and the dispersing electrode was held in place on the foot. Forty contractions were elicited per minute in a rhythmic pattern.

In a previous study[2] an investigation was made as to the effects of hot foment applications upon the volume blood flow in the extremities of anesthetized dogs. These studies have been extended and compared with those on unanesthetized animals. Experiments were carried out on normally innervated, denervated and spastic limbs. In addition, studies were made on normally innervated limbs which were treated with butyl aminobenzoate (Butesin^{R}) applied in the following manner: After the blood flow had leveled to control a three per cent solution of butyl aminobenzoate (Butesin^{R}) in sesame oil was painted on the shaved skin of the hind limb. After five minutes the excess was wiped off and a second application made. This procedure was repeated three times and at the end of the fifteen-minute period of control flow hot packs were applied. They consisted of a double thickness of munsingwear and were wrung from water at temperature ranging from 70 to 75 degrees C. The pack was then wrapped around the leg over the gastrocnemius muscle, and covered with oil silk and blanketing. A series of three hot packs were applied. The first and second packs were replaced after two minutes and the third was left in place for five minutes so that the total heating time was nine minutes. The temperature of the hot pack was measured by the insertion of a mercury thermometer into the pack. Temperature changes in the subcutaneous tissue were measured by means of an iron-constantan thermocouple needle[4] inserted into the desired position. The potentials were read every minute on a Leeds-Northrup potentiometer. Control values for blood flow were taken for fifteen minutes before the hot packs were applied. After removing the pack, the blood flow was followed until it returned to or approached control values whenever possible. When unanesthetized animals were used, the experiment had to be terminated five minutes after the re-

4. Tuttle, W. W., and Janney, C. D.: The Construction, Calibration, and Use of Thermocouples for Measuring Body Temperatures, Arch. Phys. Med. 29:416 (July) 1948.

moval of the third pack because of difficulties encountered in keeping the animals quiet for longer periods of time.

Results

The recordings of blood flow were made at two chart speeds. At fast speed, each vertical line represented 2.5 seconds and at slow speed; time was marked in minute intervals at the bottom of the records.

Chart 1 is a sample record showing the changes in volume blood flow produced during and following the five-minute period of deep stroking and

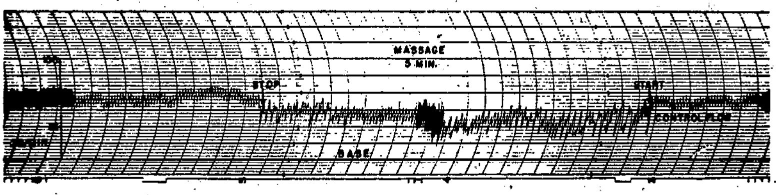

Chart 1. — Record showing effect upon volume blood flow of a five-minute period of deep stroking and kneading massage.

kneading massage. During the massage a slight decrease in the arterial volume blood flow was found. At the end of the period of massage, the flow returned to or increased slightly, but not significantly, above the control flow. Evidence presented indicates that massage of the deep effleurage and petrissage types has very little effect upon the volume blood flow in the femoral artery of dogs. The slight decrease found during the massage was probably related to a compression of the vessels from the massage movements. These results agreed essentially with those found by Wakim, et al.[5] In view of this it seems that the clinical improvement found in conditions for which massage has been shown to be beneficial must be due to some physiologic factor other than an increased blood flow.

A typical blood flow record obtained during and following the stretching of a normal limb can be seen in chart 2. During stretching there was some increase in volume blood flow. Immediately following the stretching the flow was markedly increased, reaching a maximum in about thirty seconds. The per cent changes in volume flow resulting from stretching normal, denervated and spastic limbs were compared graphically (chart 3) and analyzed statistically. Both spastic and normal limbs responded to the stretching with significant increases in the volume blood flow. The spastic limbs showed the greater increase although there was no statistical difference between these and the normals. The duration of the increases in the spastic extremities was three to seven minutes, whereas all the normals had returned to control at the end of three minutes. No significant changes in blood flow occurred when denervated limbs were stretched.

Faradic stimuli at a frequency of sixty per second produced similar effects upon blood flow regardless of whether they were applied to the nerve or directly to the muscle (charts 4 and 5). Immediately upon contraction the volume blood flow in the femoral artery was diminished and remained substantially below control until the stimulus was removed. At this time the flow was markedly increased above the resting level and only gradually returned to control levels. When muscle was activated by a clinical stimula-

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5. Wakim, K. G.; Martin, G. M.; Terrier, J. C.; Elkins, E. C., and Krusen, F. H.: The Effects of Massage on the Circulation in Normal and Paralyzed Extremities, Arch. Phys. Med. 30:135 (March) 1949.

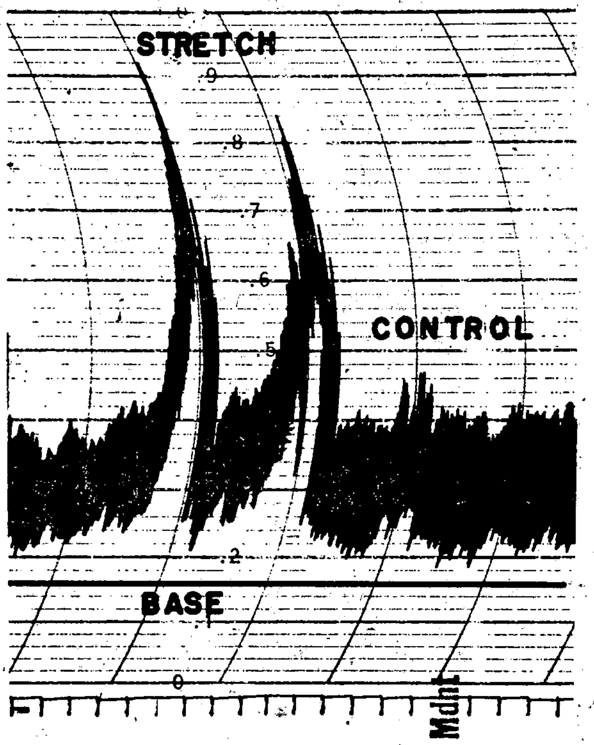

Chart 2. — Record showing changes in blood flow during and following passive stretching of a normal extremity.

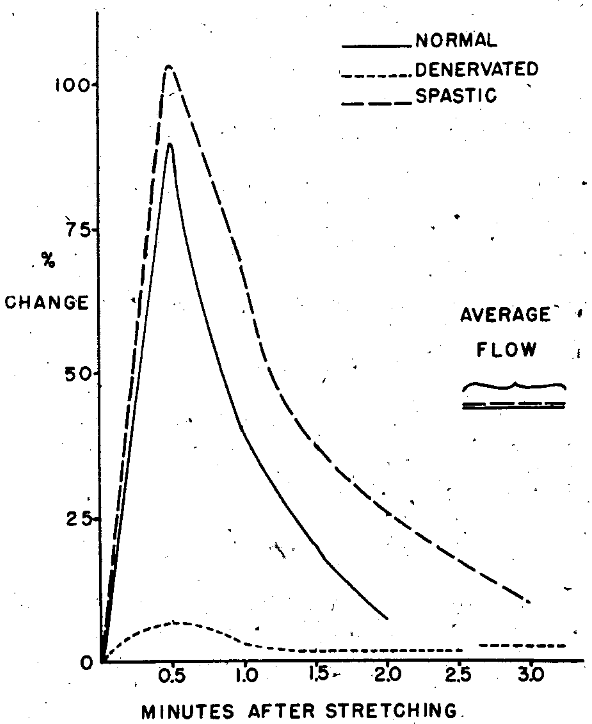

Chart 3. — Effect of passive stretching upon volume blood flow in the limb of dogs under various experimental conditions. Control flows were 62 cc./min. in normals, 56 cc./min. in spastic, and 49 cc./min. in denervated limbs.

tor which delivered stimuli in a rhythmic pattern at a frequency of forty per second there occurred a diminution of flow during contraction followed by augmentation during relaxation. After the stimulation was discontinued the flow gradually returned to the pre-stimulation level (chart 6).

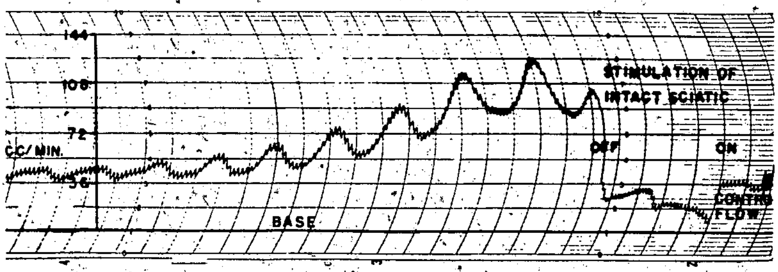

Chart 4. — Record showing changes in volume blood flow during and following indirect muscle stimulation through the nerve using faradic current and shielded electrodes.

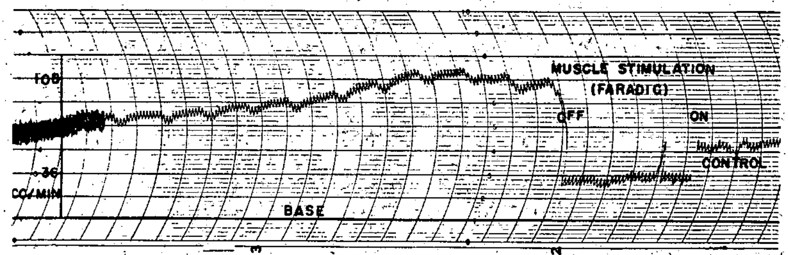

Chart 5. — Record showing changes in volume blood flow during and following direct muscle stimulation using faradic current and needle electrodes.

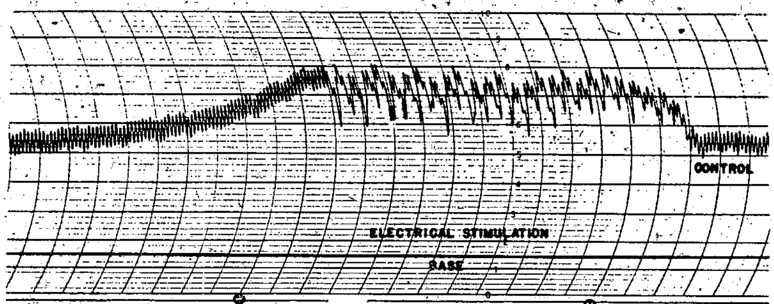

Chart 6. — Record showing changes in volume blood flow during and following rhythmic muscle stimulation using sinusoidal current pulsating at a rate of forty times per minute.

The results of the experiments in which a series of three consecutive hot packs were applied to the normally innervated, Butesin ® treated and denervated limbs of anesthetized and of unanesthetized animals together with their statistical analysis are presented in table 1. In the experiments on normally innervated limbs of animals under anesthesia the volume blood flow increased gradually from the time the first hot pack was applied, the increase becoming significant at the end of three minutes. The maximum flow was attained between two and five minutes after the third pack had been removed. Fifteen minutes after packing, the increases in blood flow were no longer significant although in some animals the flow did not return to control level for as long as forty minutes. The maximum average subcutaneous temperature increase was 8.7 degrees C., attained during the fifth minute of heating (table 2). After this the temperature gradually decreased, although the blood flow continued to increase for some time. The normally innervated limbs of unanesthetized animals showed no significant increases in blood flow during the packing. In the fifth minute following the removal of the third pack a significant increase in blood flow was observed. The average maximum increase in subcutaneous temperature was 5.5 degrees C. and occurred during the seventh minute of packing.

TABLE 1. — *Summary of Changes in Blood Flow During and Following Hot Packs.*

	— Per Cent Change in Flow —								
	Minutes During Packing				Minutes Following Packing				
Control cc./Min.	3	5	7	9	1	2	5	10	15
			A. Normally Innervated						
Anesthetized —									
Mean 43	+30	+41	+54	+60	+70	+73	+72	+48	+35
S. D.	22	36	27	46	46	59	61	47	41
t	3.6	3.1	5.2	3.5	4.0	3.3	3.1	2.8	2.1
Level of sig. ..	2	3	1	2	1	2	3	4	10
Unanesthetized —									
Mean 63	+3	+7	+3	+6	+9	+14	+18	....	....
S. D.	8	14	18	18	18	19	17	....	....
t	1.0	1.3	0.4	0.9	1.2	1.8	2.8	....	....
Level of sig. ..	40	20	80	50	30	20	4	....	....
			B. Butesin-Treated						
Anesthetized —									
Mean 36	—2	—3	+3	0	+4	+12	+17	+5	....
S. D.	15	17	22	22	26	24	28	34	....
t	0.3	0.5	0.3	0.0	0.4	1.4	1.6	0.4	....
Level of sig. ..	80	70	80	100	70	20	20	70	....
Unanesthetized —									
Mean 47	—7	—16	—11	—12	—12	—8	+3	....	....
S. D.	15	15	15	19	19	19	21	....	....
t	1.2	2.6	1.9	1.6	1.7	1.1	0.3	....	....
Level of sig. ..	30	5	10	20	20	40	80	....	....
			C. Denervated						
Anesthetized —									
Mean 32	+2	0	+16	+27	+34	+42	+45	+48	+44
S. D.	12	17	22	35	24	21	14	22	37
t	0.4	0.0	1.7	1.9	3.5	5.0	7.7	5.2	2.8
Level of sig ..	80	100	20	20	2	1	0.1	1	4
Unanesthetized —									
Mean 44	0	+1	+6	+14	+21	+37	+40	....	....
S. D.	4	4	7	10	15	23	23	....	....
t	0.0	0.6	2.3	3.8	3.9	4.5	4.8	....	....
Level of sig. ..	100	60	10	1	1	1	0.1	....	....

The volume blood flow in the limbs to which Butesin[R] had been applied showed no consistent or significant increase either during or following the application of hot foments. This was true for the experiments on both unanesthetized and anesthetized animals. The thermal pattern of subcutaneous temperature changes in Butesin[R] treated limbs was not significantly different from that found in untreated limbs.

The response of volume blood flow in the denervated limbs to the application of hot foments was similar in anesthetized and unanesthetized animals. Both showed significant increases in volume blood flow at the end of the packing period. No difference was found between these two groups at any time during or following packing. The average increase in blood flow was greater in normally innervated than in denervated limbs of anesthetized animals. There was no significant difference in the blood flow changes due to the application of hot foments in the normally innervated limbs as compared with that of the denervated limbs of unanesthetized animals.

It was difficult to evaluate the effects of the application of hot foments upon the volume blood flow in spastic limbs. During the nine minutes of packing the animals were extremely restless, so that artifacts from movements of the limb were introduced. The first minute after the removal of the final pack there was a ten per cent increase in volume blood flow over the control, a value which was significant. However, this may have been due, at least in part, to the after effects of augmented muscular tone and contraction. The fact that general anesthesia abolished spasticity prevented the carrying out of experiments on anesthetized animals.

TABLE 2. — *Increases in Subcutaneous Temperature During and Following Hot Packs.*

	Control °C	Minutes During Packing 1 °C	3 °C	5 °C	7 °C	9 °C	Minutes Following Packing 1 °C	2 °C	5 °C	10 °C
A. Normally Innervated										
Anesthetized —										
Mean	35.8	5.2	7.6	8.7	7.9	7.1	3.3	2.3	1.0	1.0
S. D.		2.3	3.1	2.8	2.3	1.4	1.7	0.8	1.3	1.2
t		5.4	5.9	7.9	8.1	19.7	4.7	6.6	2.0	2.1
Level of sig.		1.0	1.0	0.1	0.1	0.1	1.0	1.0	20.0	20.0
Unanesthetized —										
Mean	38.2	2.4	4.1	5.4	5.5	5.0	1.8	0.9	0.8	0.4
S. D.		0.7	0.8	1.4	1.5	1.9	1.0	0.9	0.9	0.8
t		9.6	14.6	11.0	10.0	7.4	5.1	0.9	2.5	0.5
Level of sig.		0.1	0.1	0.1	0.1	0.1	1.0	40.0	5.0	80.0
B. Butesin-Treated										
Anesthetized —										
Mean	36.2	3.2	6.5	7.7	7.1	6.3	3.3	1.6	0.7	0.5
S. D.		2.1	3.6	3.3	2.5	2.7	1.8	1.6	1.6	1.6
t		4.2	3.6	4.5	4.5	4.9	3.6	3.1	0.9	0.6
Level of sig.		3.0	4.0	3.0	3.0	2.0	4.0	10.0	50.0	60.0
Unanesthetized —										
Mean	38.3	3.3	4.7	5.7	4.6	4.5	1.6	1.1	1.2	1.1
S. D.		1.3	1.1	1.5	1.7	1.6	1.0	1.0	0.9	1.2
t		7.5	10.9	11.0	7.9	7.9	13.3	4.0	2.6	2.0
Level of sig.		0.1	0.1	0.1	0.1	0.1	0.1	1.0	4.0	10.0
C. Denervated										
Anesthetized —										
Mean	36.9	4.2	7.3	7.9	7.2	5.6	1.9	0.8	0.6	0.9
S. D.		2.5	4.5	2.7	1.9	1.1	1.3	1.1	1.1	1.1
t		3.5	3.3	5.6	7.7	9.8	2.7	1.3	1.1	1.4
Level of sig.		5.0	5.0	2.0	1.0	0.1	10.0	30.0	40.0	30.0

Comment

Caution must be exercised in interpreting the significances of changes in the volume flow through the femoral artery. The greater part but by no means all of the blood flow traverses the muscular structures of the limb. It is entirely possible that small but significant changes might occur, due to alterations in the flow through the skin without concomitant changes in the deeper structures. The method employed yields accurate information concerning the total over-all flow and its changes but offers no information concerning its differential distribution between the several tissues supplied by a vessel.

The finding that passive stretching was effective for increasing the blood flow through normally innervated limbs but not through denervated limbs suggests that peripheral dilatation may result from the increased metabolism associated with exaggerated myotatic reflexes rather than from the physical effects of stretching per se. In this connection, it is pertinent to point out that massage techniques short of those involving some degree of stretching have been found to be ineffective measures for increasing blood flow.

In a previous study[3] it was found that the application of electromagnetic waves to a limb resulted in an increased blood flow only providing a certain critical temperature rise occurred in the muscles. Under the condition of our experiments deep tissue temperatures were seldom found to equal or excel this level. The observation that the application of hot packs caused an increase in blood flow in the limbs of anesthetized but not in the limbs of unanesthetized animals requires comment. The average control temperature in the subcutaneous tissue in anesthetized animals was 35.8 degrees C. and the average maximum temperature reached was 44.5 degrees C., or an increase of 8.7 degrees C. In the unanesthetized group the average control was 38.2 degrees C. and the maximum temperature reached averaged 43.7 degrees C., an increase of 5.5 degrees C. It may be assumed that a greater degree of initial vasoconstriction existed in the former than in the latter. The reaction to the application of hot foments is in part due to the direct effects of heat on the smooth muscle of blood vessels and in part due to reflex effects. The application of hot foments may serve as a noxious stimulus, eliciting a protective vasoconstrictor reflex. It is logical to assume that anesthesia may unequally affect the protective and heat-dissipating reflexes.

It is quite clear from numerous studies that it is possible to increase the blood flow through tissues by such measures as the application of heat, exercise, stretching and electrical stimulation. It is also apparent that the procedures effective for increasing blood flow increase the level of metabolic activity in the affected tissue. For instance, it has been found that a rise of 10 degrees C. serves to approximately double the rate of metabolism in tissue and that the oxygen requirements of muscle may increase several fold during exercise. Is the augmented blood flow resulting from the use of these physical therapies sufficient to meet the additional metabolic requirements imposed upon tissue by the therapeutic agents? It is quite possible that in many instances they may serve to aggravate rather than to improve the effective circulatory condition of tissue. Only when the net effects of blood flow changes upon oxygen and carbon dioxide tensions and glucose concentration in tissue have been determined will it be possible to evaluate the efficacy of such physical therapies.

Conclusions

The following conclusions are drawn as to the effects of several physical therapy measures upon the volume blood flow through the femoral artery of dogs:

1. Massage proved to be an inffective measure for increasing blood flow.
2. Passive stretching caused a significant increase in blood flow in normally innervated and spastic but not in denervated limbs.
3. Electrical stimulation of muscle results in an over-all increase in

blood flow. The flow was diminished during tetanic stimulation but increased during the post-stimulation period.

4. The consecutive application of three hot packs to normally innervated limbs of anesthetized animals resulted in an increased blood flow. The increase in flow was not observed when the hot packs were applied to limbs treated with Butesin[R]. The increase in flow was greater in normally innervated than in denervated limbs. The hot foment treatments caused no significant increases in femoral arterial blood flow in normally innervated limbs of unanesthetized animals. The flow was increased significantly in denervated limbs of unanesthetized dogs.

5. The question is discussed as to whether the increases in blood flow were able fully to compensate for the augmented metabolism resulting from increase in temperature and muscular activity.

Discussion

Dr. Herbert W. Park (Fishersville, Va.): I think we have heard a very interesting and timely paper concerning the various methods for increasing peripheral blood flow in physiological conditions and compared analysis of the findings. Since impairment of blood flow is one of the significant disorders we have to deal with in our practice of physical medicine, we should consider the results reported very carefully. As Dr. Hines indicated, in various surgical and drug techniques for increasing blood flow, there are certain untoward side effects and shortcomings which either limit their use or make them unfeasible for treatment. In order to apply adequately the information given, we as physicians must of necessity make proper selection of various methods of treatment on the basis of the condition being treated, with full knowledge of the action of the agents being employed. We would like to ask Dr. Hines some questions. 1. Can he answer the perennial question concerning methods of measuring under experimental conditions where only a sampling of blood flow can be done; in other words, has he any information concerning deep circulation as compared with the superficial? 2. From a clinical standpoint quite often we find that although certain results are obtained from animal experiments, their transfer to humans is not possible; we would like to know how well he feels his results can be applied to human physiological conditions. 3. From the physiological standpoint I would like to know his opinion as to which agents are most effective, taking into consideration the various side reactions and metabolic effect. 4. I would like to know if he has done any work in measuring blood flow in the denervated muscle, using medical stimulation. I think this work is very important as far as paraplegics are concerned; I see a great number of them and I know that quite a few in this group do, too. It would be interesting to have a little information regarding the effect of artificial stimulation of blood flow in denervated muscles.

Dr. Hines (closing): It is quite evident that the factors which affect the flow of lymph in the extremities are not necessarily the same for skin and for deep tissues. In some unpublished studies, we have shown that heat causes the usual responses in blood flow when the skin of the animal was removed and replaced with a paraffin coating. However, this is not true in all cases. Whether or not these same findings occur in humans is a matter of conjecture. We applied the same dosages and modes of administration to animals as have been recommended for human subjects. We have not as yet completed any work on denervated muscle.