CALORIMETRIC STUDIES OF THE EXTREMITIES

III. Clinical Data on Normal and Pathologic Subjects with Localized Vascular Disease

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INTRODUCTION

The clinical investigation of the different forms of vascular disturbances involving the extremities has been greatly hampered by the lack of exact methods for measuring the volume flow of the blood. The classic descriptions of Raynaud, Weir Mitchell, Buerger, and others, on the different forms of the localized vascular diseases leave little to be added from the purely clinical side. There is no doubt that the signs and symptoms of these disturbances are of the utmost importance and furnish information on which the final word in diagnosis, prognosis and treatment must largely rest. Data on the volume flow of blood in a given mass of tissue would be a most valuable aid in determining the degree of vascular obliteration, the amount of collateral circulation, and the vasomotor impairment, and in evaluating the different forms of treatment. The plethysmographic studies of Hewlett and Van Zwaluwenburg (5) and the calorimetric investigations of Stewart and Taylor (6, 7) have demonstrated the applicability of instrumental methods in the investigation of vascular disturbances.

The present work represents an extension of Stewart's calorimetric method in the investigation of vascular diseases. Further information has been sought on the following questions: (*a*) Can the values for the elimination of heat from the limb be accurately transposed into terms of volume flow of blood? (*b*) What is the average range of elimination of heat or volume flow of blood of the extremity in the normal subject and in the subject with obstructive vascular lesions of the extremities? (*c*) What are the effects of environmental temperature on the rate of elimination of heat in the extremity in the normal subject and the subject with vascular disease affecting the extremities?

METHOD OF INVESTIGATION

The calorimeter[1] is a container holding a known volume of water of a lower temperature than the skin, into which the hand or foot is placed. It is so constructed that the loss of heat is slight, and the corrective value is known. Certain technical improvements have been made by Kegerreis. For example, an adequate mixing device for the proper distribution of heat and water has been incorporated in the calorimeter. The method follows closely that outlined by Stewart. The temperature of the calorimeter and its contents is allowed to come into equilibrium with that of the room, which is maintained as closely as possible between 22° and 24°C. The foot is immersed and the temperature of the water noted at intervals of five minutes. The readings are tabulated and plotted on graph paper against the time readings of the experiment. They are continued long enough so that four consecutive readings, when plotted and joined, approximate a straight line. This would indicate a linear or constant relationship between the rise of temperature of the water and the time of the immersion period. A curve consisting of two portions is thus constructed. The first or rapidly rising portion represents largely the loss of *a*, the metabolic and inherent tissue heat, and *b*, the heat given off from the surface blood.[2] Vasomotor equilibrium is probably established during this initial immersion period. The second portion of the curve is approximately a straight line representing the period of steady transfer of heat, and is taken to represent that due mainly to the steady loss of heat from the surface blood (fig. 4, Study II). This portion of the curve is considered to furnish the significant data and has been utilized as the basis of these studies. The rise in temperature of a known volume of immersion

[1] The complete technical description of the calorimeter is given by Kegerreis in Study II of this series.

[2] The inherent heat or thermal capacity of the foot represents the heat remaining in the tissues after the arterial flow is checked.

water (4,000 cc.) for a period of twenty minutes is then converted into small calories and the rate of heat elimination is determined in calories for each minute for each square inch of surface area.[3]

Application of calorimetric data. Sheard in his studies has shown the impossibility of interpreting the loss of heat from the extremity in terms of volume flow of blood. Accurate data on the volume flow of blood, although most desirable, is not essential. The amount of heat eliminated for a unit of surface area is probably of equal clinical value, since there is a close relationship between volume flow of blood and loss of heat. Too many unknown factors exist to attempt to define this relationship. The problem then, from the clinical standpoint, was to determine: (*a*) the average range of heat elimination in small calories in the feet in a group of normal subjects; (*b*) the effects of environmental temperature on the rate of heat elimination, and (*c*) the range of heat elimination in a group of patients with proved obstructive arterial disease, that is, thrombo-angiitis obliterans. It was felt that comparison of the data of the normal and pathologic subjects would determine the diagnostic value of this method, especially when controlled by studies on the effect of different environmental temperatures on the rate of heat elimination.

Routine of determinations. The ambulant subjects were allowed to rest in the sitting posture with feet bared, in the calorimetric room for a period of thirty minutes. This preliminary step was found to be unnecessary for the patients in the hospital. The usual diet was allowed. The actual room temperature during the majority of determinations varied from 22° to 26°C. When repeated determinations were carried out on the same foot, an intermission period of at least one hour was allowed. After shorter intermissions the rate of loss of heat was lower, as would be anticipated from the cooling of the skin by the immersion and subsequent evaporation.

Precautions necessary in determinations. Muscular movement in the immersed foot increases the rate of liberation and elimination of heat so the patient is instructed to keep the foot quiet and relaxed. A comfortable sitting position for the patient is necessary as

[3] The area of the foot is determined by a method devised by Kegerreis and described in Study II. The area in square inches can be converted to square centimeters by multiplying by 6.45.

the experiment frequently lasts an hour or longer. Changes in room temperature due to the opening and closing of doors should be obviated as much as possible. Environmental temperature proved to be the most disturbing factor in making determinations. During the period of excessively hot weather comparative determinations were impossible. High rates of elimination of heat were obtained in the normal controls. It was found that when the outdoor temperature was high and the room temperature within working range, normal persons maintained increased heat values for variable periods of time after coming indoors. All data recorded during the hot weather have been discarded except those necessary to determine temperature effects. The barometric pressure seems to exert no significant influence on heat elimination.

MATERIAL STUDIED

Normal group (*table 1*). Comparative calorimetric studies of the feet were carried out under controlled conditions in twenty-two normal persons whose ages varied from fifteen to fifty-four years. The incidence of males and females was about equal. Repeated daily determinations in a normal boy, aged sixteen, were carried out for four days in August (table 2). The outdoor temperature during this period ranged from 22.2° to 28.6°C. with approximately the same fluctuations indoors. A similar series of determinations was made on a normal girl during the latter portion of the same month (table 3). The outdoor temperature ranged from 18.2° to 27.4°C., with closely approximating values for the room temperature. The pulse rate, blood pressure and mouth temperature were noted.

Pathologic group (*table 4*). Sixteen cases of thrombo-angiitis obliterans (Buerger's disease), four cases of Raynaud's disease affecting the feet, and seven cases of spastic paraplegia were studied. The clinical diagnosis of Buerger's disease rested largely on the age, sex and history of the patient, and on the lack of calcification in the arteries as determined by the roentgen ray. Each patient showed definite evidence of a chronic obliterative lesion of the main arteries of the feet, as no pulsation was felt in the vessels. This observation was confirmed in oscillometric readings with the apparatus of Pachon. All these patients showed varying degrees of trophic disturbances, and about half had frank gangrene. The feet were cold, and all showed the characteristic redness of the skin accentuated by allowing the feet to assume the pendent position. In six cases amputation was performed subsequently and the characteristic pathologic lesions of this disease were found.

RESULTS

Normal subjects. Table 1 shows the range of loss of heat from the feet in ambulant and hospital subjects as measured in calories for each minute for each square inch of surface area. These data demonstrate that with the room temperature varying from 21.2° to 29.1°C. the heat eliminated during the initial determination varies widely (from 0.35 to 3.89 calories). With the room temperature between 22° and 26°C. the range of loss of heat is more restricted, varying from 0.46 to 1.15 calories for each minute for each square inch of surface area. The outdoor temperature varied from 5.2° to 32.1°C. The lowest values for loss of heat were obtained during the period of low outdoor temperatures.

Repeated determinations were made in one subject (case 10) on the right foot with the room temperature varying from 21.8° to 23.9°C. and the outdoor temperature varying from 5.2° to 19°C. Marked variations in the rate of loss of heat were found; the lowest rate was 0.13 and the highest 0.54 calories. The lower rates were obtained with low outdoor temperatures.

In figure 1 the heat in calories lost each minute for each square inch of surface area in a larger series of cases is plotted against room temperature. It will be observed that in the majority of determinations within the temperature range of 21.5° to 26.0°C., the values for loss of heat vary from 0.4 to 1.5 calories. It is noted that the relationship between the loss of heat and room temperature is roughly a linear one with the room temperature between 21.5° and 27.0°C. Above this temperature there is less loss of heat with a flattening out in the theoretic curve. In these experiments the variation in the rates of elimination by normal subjects is 350 per cent, under a restricted environmental temperature (21° to 26°C.). Subjects examined during the cooler months of the year and under hospital restrictions have shown a narrower range of heat elimination.

Determinations on the same subject with comparable room temperatures give quite closely approximating values. Repeated determinations on the rate of heat elimination on the feet of two normal subjects, a girl and a boy, aged seventeen and sixteen, respectively, were made over a period of a month when there were weather varia-

TABLE 1

Calorimetric determinations in right foot of normal subjects at rest

Case	Sex	Age	Blood pressure		Pulse rate	Temperature			Total calories lost in twenty minutes	Surface area of foot	Calories lost each minute for each square inch
			Systolic	Diastolic		Mouth	Outdoor	Room			
						°F.	°C.	°C.		*square inches*	
1	F.	26	115	70	74	98.4	24.0	24.0	1,160	94	0.61
2	M.	34	120	70	72	98.6	18.8	22.4	2,240	112	1.00
3	F.	20	92	58	80	98.2	22.1	24.7	1,800	87	1.03
4	M.	15	124	90	82	98.8	14.1	22.0	2,340	101	1.15
5	M.	50	114	70	78	99.5	37.2	22.8	1,800	79	1.14
6	F.	40	114	70	82	98.0	36.8	22.2	1,700	87	0.97
7	F.	27	106	62	70	98.8	7.8	21.2	1,100	77	0.71
8	M.	28	104	58	68	97.8	7.8	22.2	940	111	0.42
9	M.	51	105	92	72	98.2	31.0	30.4	1,600	100	0.80
10	M.	27	130	76	88	99.0	19.0	22.6	1,080	101	0.53
			120	80	80	98.2	6.8	23.9	1,100	101	0.54
					80	98.0	5.2	21.8	280	101	0.13
					88	98.4	6.0	23.6	460	101	0.23
11	M.	28	110	65	88	99.4	30.2	28.7	1,560	113	0.69
12	F.	42	110	70	80	98.2	24.3	23.4	1,040	75	0.70
13	M.	52	145	98	70	97.8	29.7	29.1	7,400	90	3.89
14	F.	45	120	82	72	98.2	26.0	26.0	1,060	80	0.66
15	M.	54	150	90	72	98.0	8.9	22.6	960	103	0.46
16	F.	53	140	100	74	98.2	6.8	21.2	580	82	0.35
17	M.	28	110	65	88	99.4	30.2	28.7	1,560	113	0.69
18	M.	28	122	68	86	98.4	32.1	27.2	860	113	0.38
19	M.	28	132	66	120	98.6	18.8	22.5	980	113	0.43
20	M.	22	140	80	60	98.6	14.5	22.0	700	102	0.46

tions of 15°C. The female subject, although classed as normal, was representative of the group of persons of the mild asthenic type with cool moist hands and feet who actually have abnormal vasomotor control. The difference between the temperature of the mouth and surface of the foot varied from 8° to 12°C. The blood pressure was slightly lowered. The calorimetric determinations from August 8 to 28 were fairly low, varying from 0.18 to 0.77 calories (table 2). These values existed with a fairly constant room temperature ranging from 20.3° to 25.3°C. Determinations in both feet during the same day showed remarkably close values. During the afternoon of August 28 the room temperature increased 3.4°C. and the rate of heat elimination increased from 0.65 to 1.5 calories. The lower values of loss of heat were obtained on the cooler days and higher values during the periods of warmer weather. Repeated determinations on August 12 with temperature changes of 2.3°C., or of an increase of

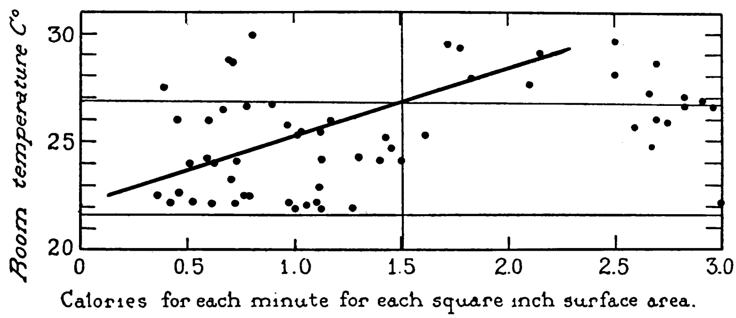

FIG. 1. RELATIONSHIP BETWEEN ROOM TEMPERATURE AND RATE OF HEAT ELIMINATION IN NORMAL SUBJECTS

Between 21.6° and 26°C. it is approximately linear. Each point represents the rate of heat elimination in a normal subject, shown on the abscissa, plotted against environmental temperature, shown on the ordinate.

10 per cent in the outdoor and room temperatures, showed an increase of 70 per cent in the loss of heat. On August 28 there was an increase of 2.7°C., or 10 per cent in the outdoor temperature, and the rate of loss of heat increased 130 per cent. The following day, without change in the outdoor or room temperature, the rate of heat elimination increased about 100 per cent.

In the second series of determinations, which was carried out on a normal boy, aged sixteen, the feet were warm, from 4° to 6°C. less than the mouth temperature (table 3). The initial calorimetric determinations showed a range of 0.52 to 2.97 calories for each square inch of surface area for each minute with the environmental

TABLE 2

Repeated calorimetric determinations in normal girl, aged seventeen

Date	Blood pressure		Pulse rate	Temperature			Foot	Total calories lost in twenty minutes	Surface area of foot	Calories lost each minute for each square inch	Remarks
	Systolic	Diastolic		Mouth	Outdoor	Room					
1924				°F.	°C.	°C.			*square inches*		
August 11	114	98	78	97.4	18.2	21.5	Right	540	90	0.30	At rest
			76	97.4	19.8	21.7	Left	440	89	0.24	At rest
	110	80	80	97.6	22.6	22.6	Right	560	90	0.31	At rest
August 12	108	80	82	96.6	20.2	21.8	Right	660	90	0.36	At rest
			90	97.6	21.6	22.3	Left	640	89	0.35	At rest
	106	60	88	98.1	22.5	23.1	Right	940	90	0.52	At rest
August 13	104	60	72	97.4	16.6	21.0	Right	340	90	0.18	Change in weather
August 15	110	64	84	98.0	19.4	20.3	Right	880	90	0.48	Twenty minutes after walking for fifteen minutes
August 27	110	74	74	98.0	23.2	23.5	Right	1,400	90	0.77	Change in weather
August 28	100	66	72	98.0	24.6	23.7	Right	1,180	90	0.65	At rest
			76	98.0	25.0	25.3	Left	1,200	89	0.67	At rest
	98	50	76	98.2	27.3	27.1	Left	2,800	89	1.5	At rest
August 29	95	60	74	98.0	27.4	24.9	Left	5,140	89	2.85	At rest

TABLE 3

Repeated calorimetric determinations in a normal boy, aged sixteen

Date	Blood pressure		Pulse rate	Temperature			Foot	Total calories lost in twenty minutes	Surface area of foot	Calories lost each minute for each square inch	Remarks
	Systolic	Dias-tolic		Mouth	Outdoor	Room					
1924				*°F.*	*°C.*	*°C.*			*square inches*		
August 4	136	92	96	99.6	28.6	28.2	Right	5,300	116	2.71	Hot sultry day
August 5			70	98.3	25.0	24.3	Right	2,940	116	1.31	Cool period of morning
			72		25.4	25.4	Left	2,240	115	0.97	Immediately after test of right foot
			70	98.4	26.4	26.1	Right	6,200	116	2.67	After rest of thirty minutes
					26.6	26.2	Right	2,060	116	0.90	Fifteen minutes after previous test
August 6			68	98.0	22.9	25.1	Right	2,400	116	1.03	After rest of thirty minutes
			72		22.8	25.0	Left	1,720	115	0.75	Immediately after previous test
	130	60	56	97.0	22.8	22.5	Right	1,420	116	0.61	After walking 504 steps
					22.2	22.7	Right	900	116	0.36	After rest of thirty minutes and decrease in room temperature
August 7	110	80	72	98.0	23.8	24.1	Right	1,760	116	0.76	After rest of thirty minutes
			84		23.4	24.2	Left	1,380	115	0.60	Immediately after previous test
			60	98.6	26.1	25.5	Right	1,400	116	0.60	Twenty-five minutes' rest after walking
August 8			72	97.0	23.6	24.0	Right	1,220	116	0.52	After rest of twenty-five minutes
			70	98.5	26.2	25.5	Left	1,060	115	0.46	Immediately after test of right foot
			70	98.5	25.8	25.8	Right	6,760	116	2.91	After rest of twenty-five minutes
			68		26.3	26.4	Right	1,840	116	0.79	Following preceding test

temperature varying from 22.5° to 28.2°C. Four determinations were carried out August 5. The outdoor temperature and room temperature ranged from 24.3° to 26.6°C. The previous day had been extremely sultry with an outdoor temperature of 28.6°C., and the heat eliminated from the right foot was 2.7 calories for each square inch for each minute. The first determination showed a rate of 1.31 calories in the right foot and 0.97 in the left. During the afternoon the outdoor and room temperatures were rising, and the right foot gave off 2.6 calories at the first determination and 0.9 calories at the second. Fifteen minutes intervened between the two determinations. The heat lost by this foot showed a variation of about 100 per cent between the morning and afternoon determinations, with a variation of environmental temperature of 2.1° or about 10 per cent. The first determinations were made during the early morning. Calorimetric studies made on the same foot after previous immersion for from thirty to sixty minutes showed a sharp reduction in the loss of heat as shown August 5. The next day the outdoor temperature had decreased 3.7°C. in twenty-four hours but the room temperature was still high, although it decreased gradually during the day, with a corresponding decrease in the rate of heat elimination. August 6 the outdoor and room temperatures increased about 10 per cent and the rate of elimination of heat in the right foot increased 600 per cent.

It will also be observed that in both of the normal subjects lower values were obtained for the left than for the right foot. The determinations were always carried out on the right foot first. This is no doubt a vasomotor effect of the cooling of the opposite extremity, the contralateral vasomotor response as noted by Stewart.

Pathologic subjects. Table 4 shows the data on the patients having thrombo-angiitis obliterans with obstructed arteries of the feet. The rate of heat elimination varied from 0.27 to 1.0 calorie with environmental temperatures ranging from 21.8° to 26°C. Repeated determinations gave similar results (table 5). It will be observed that with wide variation in the environmental temperature, the rate of heat elimination was more fixed and constant than in the normal subjects (case 4, table 5). A variation of 5.2°C. occurred in the room temperature and the rate of loss of heat was unchanged in the right foot. No clear-cut difference in the heat values was noted in the patients in the early and late stages of the disease.

Comparative determinations for evaluation of treatment. A large series of determinations have been carried out in cases of thrombo-angiitis obliterans to study the effects of various forms of treatment. The rates of heat elimination have been followed before and after

TABLE 4

Calorimetric determinations of loss of heat in the feet of subjects with thrombo-angiitis obliterans

Case	Sex	Age	Blood pressure		Pulse rate	Temperature			Foot	Total calories lost in twenty minutes	Surface area of foot	Calories lost each minute for each square inch
			Systolic	Diastolic		Mouth	Outdoor	Room				
		years				*°F.*	*°C.*	*°C.*			*square inches*	
1	M.	28	122	84	66	98.2	27.5	26.0	Right	1,520	112	0.67
2	M.	45	108	76	80	97.4	25.2	25.5	Right	1,760	88	1.00
3	M.	41	100	66	70	98.4	24.7	25.5	Left	1,540	97	0.79
4	M.	36	110	76	80	98.4	13.7	24.0	Right	1,580	102	0.77
5	M.	26	130	66	86	99.4*	9.2	24.0	Left	7,400	118	1.13
6	M.	45	110	85	80	98.5	−1.6	22.2	Left	1,520	110	0.69
									Left			0.64
7	M.	42	120	78	80	97.6	0	22.0	Left	640	93	0.39
									Left			0.30
8	M.	37	122	86	86	98.0	−9	21.9	Left	1,300	113	0.57
9	M.	42	94	60	60	98.0	−4	21.8	Left	1,100	99	0.55
10	M.	37	101	68	78	97.8	−4.6	22.6	Left	640	104	0.30
									Right	540	100	0.27
11	M.	45	128	82	80	98.6	−3	23.0	Left	1,480	112	0.66
									Left			0.54
12	M.	49	126	86	82	96.0	6	22.3	Left	1,080	117	0.46
13	M.	39	102	64	68	97.0	−4	22.0	Right	880	102	0.43
14	M.	33	90	54	84	97.8	12.3	22.0	Left	1,000	101	0.50
15	M.	50			70	97.0	11.1	22.1	Right	2,400	113	1.06
16	M.	44	120	60	76	97.5	23.2	23.2	Right	1,480	108	0.68

* Slight fever.

intravenous injection of sodium citrate, hypertonic salt solution, and radium chlorid, and after the oral ingestion of large quantities of Ringer's solution. No changes in the rate of loss of heat could be shown, although varying degrees of relief from pain were noted. Table 6 shows the rates of heat elimination of the feet in three cases of spastic paraplegia in which lumbar ganglionectomy was per-

TABLE 5

*Comparative determinations of loss of heat of the feet in cases of thrombo-angiitis obliterans**

Case	Date	Sex	Age	Blood pressure		Pulse rate	Temperatue			Foot	Total calories lost in twenty minutes	Surface area of foot	Calories lost each minute for each square inch
				Systolic	Diastolic		Mouth	Outdoor	Room				
	1924						°F.	°C.	°C.			*square inches*	
1	June 30	M.	49	116	80	85	97.0	16.9	22.0	Right	1,680	98	0.85
				142	88	89	97.8	17.8	21.8	Left	1,800	105	0.85
	July 1			118	80	89	98.0	18.5	21.8	Left	1,420	105	0.67
	July 7			116	78	72	98.2	25.0	24.4	Left	1,000	105	0.47
	July 9			140	90	86	96.0	22.3		Right	1,460	98	0.74
2	July 25	M.	30	112	80	90	98.0	25.4	24.8	Left	1,180	108	0.52
	July 29			104	64	87	99.0	24.8	24.6	Left	1,100	108	0.51
	August 11			114	88	80	98.4	23.4	22.8	Left	920	108	0.42
3	November 28	M.	37	122	86	86	98.0	−9.5	21.9	Left	1,300	113	0.57
	1926												
	April 27			114	68	72	97.0	3.0	22.4	Left	1,400	98	0.76
	1925												
4	June 1	M.	43	128	78	78	98.6	27.6	27.2	Right	2,000	105	0.95
	June 5			120	68	98	99.0	28.7	27.8	Left†	5,660	97	2.91
	June 8			118	68	76	97.4	16.8	22.3	Left	2,300	97	1.18
	1926												
	January 27					78	98.0	−14.0	22.0	Right	2,120	105	1.00

* Note the relative constancy of the heat elimination.

† No vascular occlusion in left foot.

formed by Adson for its effect on muscle tone (4). Large increases in the rate uniformly followed operation. In consequence of these observations this operation was tried by Adson (1) in cases of Raynaud's disease to relieve the vasospastic disturbance, and large increases in the loss of heat were noted. In cases of thrombo-angiitis obliterans,

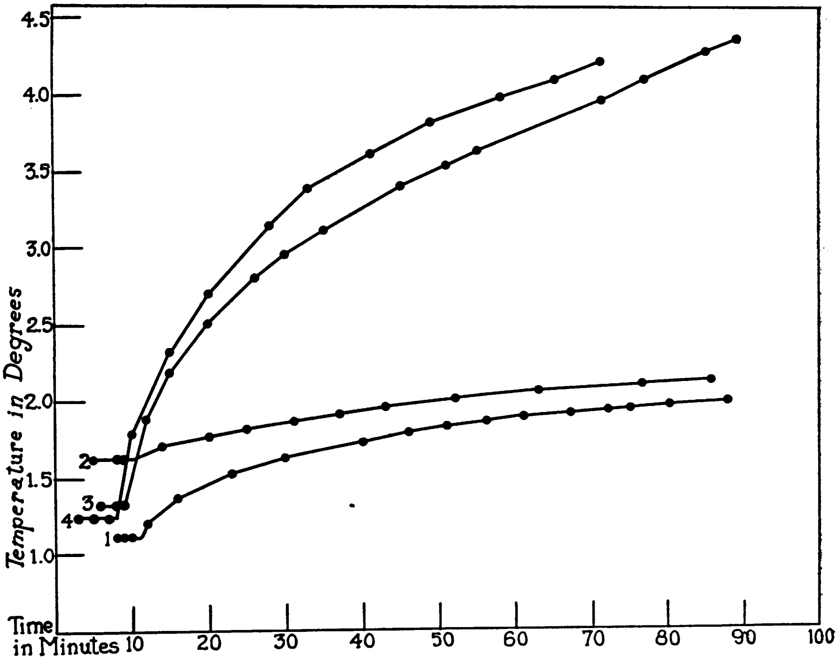

FIG. 2. CURVES OF HEAT ELIMINATION IN NORMAL AND PATHOLOGIC SUBJECTS

Curve 1. Raynaud's Disease.
Curve 2. Thrombo-angiitis obliterans.
Curve 3. Normal Subject.
Curve 4. Erythromelalgia.

Note the close parallelism in loss of heat between Raynaud's disease and thrombo-angiitis obliterans.

increased vasodilatation and increased loss of heat were noted, although not to the degree observed in the non-obliterative types of vascular disturbance. The injection of intravenous protein (typhoid bacilli) produced large but temporary increases in the rate of heat elimination in certain cases of Buerger's disease (table 6).

TABLE 6

Comparative determinations of loss of heat in the feet following surgical and medical treatment

Case	Sex	Age	Diagnosis	Date	Blood pressure: Systolic	Blood pressure: Diastolic	Pulse rate	Temperature: Mouth	Temperature: Outdoor	Temperature: Room	Foot	Total calories lost in twenty minutes	Surface area of foot	Calories lost each minute for each square inch	Remarks
		years		*1925*				°F.	°C.	°C.			*square inches*		
1	F.	28	Spastic paraplegia	February 24	130	80	100	97.9	0	23.3	Right	560	69	0.40	Before operation
				February 25	128	80	85	97.7	−9.3	19.0	Right	400	69	0.29	Before operation
				March 19			84	97.9	4.2	22.2	Right	1,480	69	1.07	After lumbar sympathetic neurectomy
				April 6	114	86	72	97.7	21.7	22.4	Right	1,760	69	1.13	After lumbar sympathetic neurectomy
2	M.	43	Spastic paraplegia	March 9	128	80	68	97.0	21.7	24.0	Left	1,400	95	0.73	Before operation
							70	97.9	21.7	24.0	Left	1,360	95	0.71	
				April 6	114	64	84	98.2	21.6	22.3	Left	7,720	95	4.06	After lumbar sympathetic neurectomy
				April 8	100	66	80	97.9	19.0	25.0	Left	5,700	95	3.00	
				1926											
3	M.	28	Spastic paraplegia	February 16	98	60	76	98.2	13.0	23.0	Right	1,100	110	0.47	Before operation
				February 17	98	64	72	98.1	−2.7	22.0	Right	600	110	0.27	
				March 9	100	60	70	97.0	−1.0	22.3	Right	3,000	110	1.36	After lumbar sympathetic neurectomy
				1925											
4	F.	?	Raynaud's disease	October 6	96	70	86	98.8		22.5	Right	740	83	0.44	Before operation
				October 23	86	80	86	98.8	20.0	22.6	Right	2,200	83	1.32	After lumbar sympathetic neurectomy
					86	60	88	98.8	20.0	22.3	Right	1,760	83	1.06	

				1926											
5	M.	54	Buerger's disease	February 4	110	60	72	98.6	−9.4	22.0	Right	960	115	0.41	Before operation
					110	60	72	98.6	−9.4	22.0	Right	940	115	0.40	
				April 1	116	60	80	97.9	4.0	22.6	Right	1,380	115	0.60	After lumbar sympathetic neurectomy
				April 2	116	60	70	98.6	6.5	22.8	Right	1,600	115	0.64	
6	M.	34	Buerger's disease	March 30	136	80	72	97.7	0	22.6	Right	1,200	104	0.57	At rest
				March 25	130	80	80	102.2	−2.0	22.3	Right	4,600	104	2.21	Following the injection of 35,000,000 typhoid bacilli

DISCUSSION

Heat is eliminated from the body in different ways, through the excreta, expired air, evaporation of sweat, and by conduction and radiation from the skin. Vierordt (8) has estimated the relative values of these agencies in causing loss of heat as follows: urine and feces 1.8 per cent; expired air 10.7 per cent; evaporation from the skin 14.5 per cent, and radiation and conduction from the skin 73

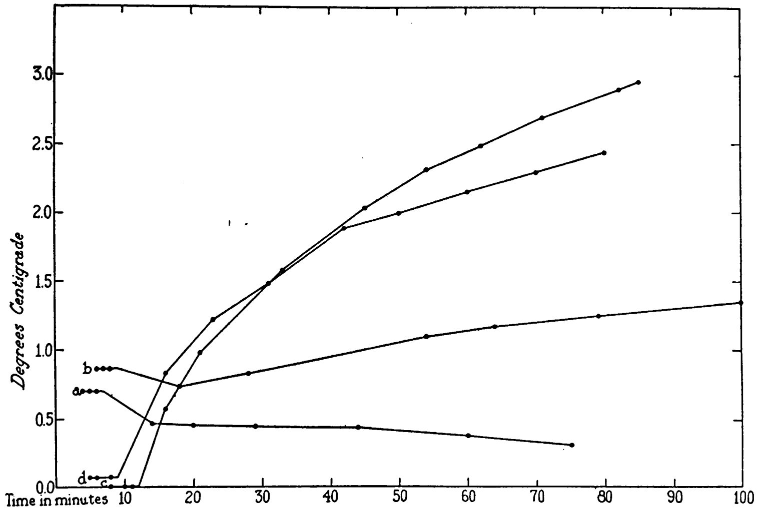

FIG. 3. INCREASED HEAT ELIMINATION IN CASE OF RAYNAUD'S DISEASE FOLLOWING LUMBAR SYMPATHETIC GANGLICNECTOMY AND PERIVASCULAR NEURECTOMY

Curves a and b. Right foot, before operation.
Curves c and d. Right foot, 16 days after operation.

per cent. In man, evaporation and radiation are largely the basis of heat regulation, the so-called physical regulation of loss of heat. The method of Stewart (6) for determining the rate of loss of heat, in which the extremity is immersed in water at a temperature lower than that of the skin, determines largely the loss of heat due to radiation and conduction rather than that due to evaporation. The source of the heat of radiation and conduction must be derived from the surface circulation, the inherent tissue heat and the cellular or metabolic heat.

Unfortunately, from the standpoint of quantitative study, the measurement of the heat output of the skin is complicated by vasomotor effects. The vasomotor mechanism is delicately adjusted to the environmental temperature; and the circulation of the surface vessels, sweat-gland activity and the blood concentration, according to Barbour (2), vary with changes in the environmental temperature. Many disturbing factors affecting the vasomotor nerves enter into this type of calorimetric work. The exposure of the feet to the air, the effects of plunging the foot into water of a lower temperature, the arrest of local perspiration, the contralateral vasomotor effect of the cooling of the opposite extremity, the compensatory after-effects of vasoconstriction illustrate some of the probable disturbances. As our data show, we have attempted to eliminate or control these disturbing agents so far as possible, but a definite limitation or absolute accuracy is impossible in this type of investigation. If an ideal type of experiment could be carried out in which the patient was adequately controlled for long periods of time under a constant environmental temperature, and perhaps an air-type of calorimeter was utilized and the various vasomotor disturbances were controlled or eliminated, data obtained would be much more accurate. For clinical purposes absolute accuracy is not required, as the range of loss of heat in both normal and pathologic subjects is wide. With a restricted environmental temperature comparative determinations show fairly consistent values by the Stewart-Kegerreis method.

Sheard's analyses of the heat curves apparently show that the temperature curve of the immersion water can be divided into two portions: *a*, the rapidly rising, and *b*, the straight or linear. He has shown that these differences in the curves represent heat of different origin. As information was desired relative to blood flow, the second or linear segment of the curve was used as the basis of this measurement, as this portion represents the period of steady increase or transfer of heat from skin to water. If such an experiment were carried out for a sufficient length of time the curve would approximate a straight line parallel to the time axis when the bath and surface temperature become approximately equal.

Sheard's data seem to show that the loss of heat as measured in small calories cannot be interpreted in terms of volume flow of blood because of the lack of information on the conduction and radiation properties of the skin and subcutaneous tissue, the number and size of the surface vessels, and the rate of capillary flow. The difference in temperature between the surface blood and the immersion bath plays a part in determining the rate of loss of heat. The effects on the rate of heat elimination, of changing the conduction properties of the surface, can be verified by the simple expedient of covering the foot with an insulating material such as paraffin. Sharp decreases in the rate of heat elimination will then occur, with no evidence that the blood flow in the central part of the foot has been disturbed in the least. If the skin and subcutaneous tissues were susceptible of analysis as to their specific heat and conductivity constants, and the capillary factors were susceptible of measurement in the individual case, the values for loss of heat could then be transferred into terms of volume flow of blood. From the clinical aspect, the value of the method is not greatly impaired by this fact. A method has a clinical value and application when the data can be reduced to a quantitative unit and when the method can be so controlled that fairly accurate comparative data are obtainable. Many clinical procedures lack absolute value because of unevaluated factors which however are sufficiently constant to make comparative data of great significance. The estimation of blood pressure illustrates this point.

Our clinical studies on the value of the calorimetric method of investigating vascular diseases indicate clearly that under a fairly constant environmental temperature the range of heat elimination in normal subjects is fairly wide. Low rates of loss of heat are found in many apparently normal subjects with cold extremities whereas higher values are obtained in other normal subjects with warm extremities and the same environmental temperature. The so-called normal subject with cold extremities presents certain well-defined variations in the color and appearance of the skin of the acral areas. When coldness of the extremities becomes troublesome, the condition assumes a clinical interest and is designated acrocyanosis or acro-asphyxia. When pain and trophic disturbances ensue the condition is recognized clinically as Raynaud's disease. Studies of the surface capillaries by the Lombard method indicate that the vascular disturbance varies only in degree in this large group and it is frequently difficult to state where abnormality begins (3). The main arteries of the limb seem normal and have the usual amplitude of pulsation as determined by the oscillometer. There is no indication that the volume flow of blood entering the hand or foot is significantly diminished. This disturbance of a vasospastic nature seems to be confined largely to the peripheral arterioles, capillaries and venules of the skin, with a diminished flow of surface blood and thus a diminished loss of heat. There is some evidence that a portion of the arterial blood is shunted through the deeper arteriole channels. Thus it is clear why in many so-called normal subjects with patent arteries of the feet, the rates of heat elimination as measured in small calories of heat are as low as in subjects with obliterative vascular disease. The apparent paradox is explained by the fact that an adequate or marked collateral circulation is established in the latter cases. With gangrene of a small portion of the foot, such as a toe, the circulation for a small segment of tissue would be inadequate, but not in a degree to decrease markedly the loss of heat of the foot as a whole nor to influence significantly the calorimetric data. I have obtained low normal values of loss of heat in the foot with well-defined gangrene of one or more toes. From the standpoint of diagnosis the values of heat loss are not pathognomonic, although, generally speaking, normal subjects have higher rates of heat elimination than subjects with thrombo-angiitis obliterans and lower rates than certain subjects with polycythemia vera. There is an intermediate range of values in which the groups overlap.

The vasomotor responses of the normal subject and of the subject with thrombo-angiitis obliterans to elevations in the environmental temperature are strikingly different, as noted in our data. The normal subject shows marked vasomotor response with changes in the room temperature; these variations as measured in loss of heat reach several hundred per cent in magnitude. Repeated determinations on the pathologic subject indicate a more constant rate of loss of heat, and the vasomotor responses with changes in environmental temperature are less. The local circulation is theoretically maintained with vasodilatation at a high or maximal point in the extremity as a compensatory effect of arterial obliteration. It was observed however that in some cases of thrombo-angiitis obliterans vasodilatation was sufficient to be determined quantitatively by the foot calorimeter. As a result of this observation, a vascular test has been devised to determine the potential vasodilatation in response to increased systemic temperature in the different types of vascular disease; this will form the basis of a separate study. Information is thus obtained as to whether benefit would probably result from operative measures which would destroy, or produce interference with, the vasomotor nerve paths.

The calorimetric method has been of great clinical value in comparative determinations to evaluate the effects of treatment. As shown in our data, under fairly constant environmental temperatures approximately similar data are obtained in repeated determinations on any given normal or pathologic subject. The effects of various therapeutic measures have been studied, and the constancy or variation in the rates of heat elimination have been used as a basis for determining their efficacy. The effects of the intravenous injection of sodium citrate and the oral administration of large quantities of Ringer's solution were found to be nil. No changes in the loss of heat were noted in cases of thrombo-angiitis obliterans following the intravenous administration of radium chlorid, although relief from pain was noted in 50 per cent of the cases. A series of patients with Raynaud's disease and thrombo-angiitis obliterans were given intravenous injections of foreign protein (typhoid vaccine) with marked increases in the rate of heat elimination in the first group and in some of the latter group. The vasodilator effects following the removal of the second, third, and fourth lumbar sympathetic ganglia for the relief of muscle spasticity were demonstrated conclusively by the calorimetric method. This operation carried out in cases of Raynaud's disease resulted in the complete disappearance of all symptoms in the lower extremities and was associated with large increases in the rate of heat elimination. In four cases of thrombo-angiitis obliterans the rates of heat elimination were increased following lumbar ganglionectomy, but not so markedly as in the cases of spastic paraplegia or of Raynaud's disease. Calorimetric determinations have been adopted as a routine procedure in the study of localized peripheral vascular disease because of the great value of comparative studies on the rates of loss of heat.

The question naturally arises whether the calorimetric method gives more information than would the determination of surface temperature. I am of the opinion that multiple determinations of the skin temperature by an accurate technic would be of equal value. The calorimetric method has certain practical advantages since it gives the sum total of the surface heat eliminated from a large area of tissue in terms of calories lost during a unit space of time and for a unit area of surface. It gives convenient data for comparison and permits the establishment of certain approximately normal standards.

There are several disadvantages in the method. The average time for a determination is about one hour, and an exacting technic is necessary to obtain reliable data. When a room of constant temperature is not available the results are seriously interfered with by hot weather. During the excessively hot weather we have not attempted to use the method clinically.

SUMMARY

The calorimetric method of Stewart and of Kegerreis has been critically studied from the standpoint of its clinical value in the peripheral vascular diseases. It was found that the loss of heat of the extremities, as measured in small calories eliminated for each square inch of surface for each minute of time, could not be interpreted in terms of volume flow of blood. The normal range of heat elimination varies with changes in the environmental temperature. Under a restricted range of environmental temperature from 22° to 26°C., from 0.46 to 1.15 small calories of heat are eliminated for each square inch of surface area of the foot for each minute in normal subjects. In subjects with thrombo-angiitis obliterans with obstruction of the main vessels of the feet from 0.27 to 1.0 calorie of heat is eliminated. The fluctuations in loss of heat from changes in the environmental temperature are much less in patients with obstructed arteries of the feet. From the diagnostic standpoint the method has a restricted value in the study of the vascular disturbances affecting the

extremities. For comparative studies under controlled conditions the calorimetric method is of great value as it makes possible the adequate evaluation of both medical and surgical treatment.

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