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THE EFFECT OF BANDAGING OF THE LEGS ON THE RATE OF BLOOD FLOW IN THE FEET *

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It has been suggested by some observers of the condition known as "trench-foot," which was so common among the soldiers in the trenches in Belgium and France, especially during the first winter of the war, that obstruction of the venous return by the puttees worn by the British troops was an important contributory factor.

The observations which form the subject of this paper are concerned only with the effect of relatively short applications of the puttees. Having been made in a laboratory on a normal man, they do not reproduce what is probably an important condition for the development of trench-foot, if the pressure of the puttees has anything to do with the condition, namely, the swelling under an already tight, wet, and dirty bandage. So far as the technic of the observations is concerned, it would have been easy enough to study the circulatory changes at first hand on soldiers. Not having been able to do this (and of course in such matters the military authorities must be the final judges as to what military exigencies will allow), the writer is, for the present at least, obliged to content himself with publishing a few specimen results on a normal man, which he had hoped to compare with data obtained by clinical studies of the actual condition at different stages. Since, however, so far as I am aware, no investigation of the influence of such bandages applied to the legs on the flow of blood in the feet has been published, and since such measurements have an interest in other relations, the application of bandages to limbs being so common in surgery and in certain medical procedures, it seems worth while to record the result of this preliminary study.

The observations were made on M. C., a healthy man, aged 26 years, weight 165 pounds, height 5 feet, 10 inches. Numerous measurements of the blood flow in his hands and feet have been made in the past few years, so that the range of variation of the flow under the

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conditions of the observations is well known.¹ In all the experiments the amount of water in the calorimeters was 2,550 c.c. The puttees were always applied over the trousers, which were tucked in in the usual way.

October 22. M. C., four hours after breakfast, put his feet in the bath at 11:02 and in calorimeters at 11:18 a. m. The pulse was 90. At 11:40 a puttee was put on the right leg with the ordinary degree of firmness. At

TABLE 1

Time	Temperature of Calorimeters		Room Temperature	Time	Temperature of Calorimeters		Room Temperature
	Right	Left			Right	Left	
11:17	31.08	31.22		12:05	31.795	31.59	24.1
11:20	31.19	31.24	24.3	12:07	31.82	31.63	
11:22	31.24	31.27	24.3	12:09	31.85	31.65	24.1
11:24	31.28	31.29	24.3	12:11	31.88	31.675	
11:26	31.32	31.30		12:13	31.91	31.69	24.1
11:28	31.36	31.34	24.4	12:15	31.96	31.74	
11:30	31.395	31.36		12:17	32.00	31.775	24.1
11:32	31.41	31.37	24.2	12:19	32.06	31.83	
11:36	31.44	31.39	24.2	12:21	32.10	31.86	24.0
11:38	31.47	31.40	24.3	12:23	32.14	31.90	
11:40	31.495	31.43		12:25	32.19	31.94	24.1
11:48	31.52	31.44	24.2	12:27	32.23	31.97	
11:46	31.53	31.45		12:29	32.295	32.04	24.1
11:47	31.55	31.455	24.2	12:31	32.34	32.08	
11:49	31.58	31.46	24.2	12:33	32.39	32.125	24.1
11:51	31.60	31.465		12:36	32.43	32.16	
11:53	31.62	31.47	24.2	12:38	32.47	32.18	24.1
11:55	31.63	31.475		12:40	32.49	32.195	
11:57	31.66	31.485	24.2	12:42	32.50	32.22	24.1
11:59	31.68	31.50		12:44	32.52	32.24	
12:01	31.72	31.54	24.2	12:46	32.44	32.19	
12:08*	31.76	31.57		1:01	32.12	31.87	

* Right foot feels more comfortable than left, and a little warmer.

12:23 the puttee was rapidly taken off. At 12:44 the feet were removed from the calorimeters.

The cooling of the calorimeters in fifteen minutes was 0.32 C. The volume of the right foot was 1,171 c.c., of the left 1,128 c.c. The water equivalent of the calorimeters with their contents was, right 3,616 c.c., left 3,584 c.c. The rectal temperature was 36.89 C.

In Table 1 is given an experiment in which a puttee was applied only to the right leg. Since the pressure is not the only effect which

1. Stewart, G. N.: Jour. Exper. Med., **18**, 354, 372.

the bandage can exert on the blood flow, but the warmth may also be important, in other experiments puttees were applied to both legs, but with different degrees of tightness.

In this experiment the flow in the feet was less than in the others cited, possibly because the subject had been going about for some time with bare feet and legs, completing the preparations for the observations; probably also in part because the experiment was made several hours after a meal. The taking of food, since it increases metabolism, must also increase the heat loss, and therefore the vasodilatation of the skin. The initial vasoconstriction due to exposure of the feet

TABLE 2

Time	Temperature of Calorimeters		Room Temperature	Time	Temperature of Calorimeters		Room Temperature
	Right	Left			Right	Left	
2:37	30.89	30.95		3:10	32.95	32.875	
2:40	30.99	31.03	24.0	3:12	33.01	32.95	24.0
2:42	31.20	31.20	24.1	3:14	33.09	33.03	24.1
2:44	31.40	31.39	24.2	3:16	33.18	33.13	
2:46	31.57	31.55	24.3	3:18	33.26	33.19	24.1
2:48	31.73	31.71	24.3	3:20	33.36	33.30	
2:50	31.89	31.86		3:22	33.45	33.37	24.1
2:52	32.02	32.99		3:24	33.53	33.46	
2:56	32.24	32.18	24.1	3:26	33.61	33.55	24.1
2:58	32.33	32.28	24.1	3:28	33.70	33.65	
3:00	32.45	32.38		3:30	33.78	33.72	24.15
3:02	32.58	32.51	24.0	3:32	33.86	33.785	
3:04	32.72	32.65		3:34	33.81	33.74	
3:06	32.80	32.74	24.0	3:46	33.50	33.43	
3:08	32.88	32.80	24.0				

tended to pass off as the experiment proceeded, the rate of flow increasing in the successive periods. But there was no indication that the puttee on the right leg in any way interfered with the flow in the right foot. The ratio of the minute flow in the left foot to that in the right was almost precisely the same in the eighteen minutes before the application of the puttee as in the forty minutes during which it remained on. The data are displayed in succinct form in Table 5.

In the experiment shown in Table 2 a puttee was applied firmly to the right leg. The degree of pressure of the puttee was about what the soldier commonly employs. On the left leg a similar puttee was applied quite loosely, so that the heat-conserving effect would be the

same as on the right leg, while the pressure was negligible. For the ten minutes before the application of the puttees the flow per minute per 100 c.c. of part was 7.18 gm. for the right and 7.2 gm. for the left foot, practical equality. For twenty minutes with the puttees on, the flow was 6.43 gm. and 6.58 gm. per minute per 100 c.c. For fourteen minutes after removal of the puttees the flow was 8.09 gm. and 8.13 gm. per 100 c.c. per minute for the right and left foot respectively.

TABLE 3

Time	Temperature of Calorimeters		Room Temperature	Time	Temperature of Calorimeters		Room Temperature
	Right	Left			Right	Left	
2:36	30.87	30.88		3:17	33.33	33.22	24.2
2:38	30.93	30.97	24.1	3:19	33.40	33.27	
2:40	31.09	31.09	24.1	3:21	33.47	33.34	24.2
2:42	31.28	31.27		3:23	33.52	33.42	
2:44	31.42	31.43	24.1	3:25	33.595	33.47	24.2*
2:46	31.58	31.55		3:27	33.65	33.54	24.25
2:48	31.70	31.68	24.0	3:29	33.72	33.59	
2:50	31.85	31.82		3:31	33.78	33.66	24.2
2:52	31.99	31.92	24.1	3:33	33.83	33.72	
2:54	32.12	32.055		3:35	33.90	33.79	24.2
2:56	32.25	32.16	24.1	3:37	33.97	33.86	
3:00	32.41	32.34	24.3	3:39	34.02	33.915	24.2
3:02	32.53	32.45	24.25	3:41	34.07	33.96	
3:05	32.70	32.60	24.3	3:43	34.13	34.02	24.2
3:07	32.805	32.69		3:45	34.19	34.07	
3:09	32.90	32.80	24.25	3:47	34.26	34.14	24.2
3:11	33.00	32.91		3:49	34.30	34.18	
3:13	33.11	33.03	24.2	3:51	34.26	34.12	
3:15	33.22	33.13		4:05	33.90	33.76	

* Left leg felt cool after the puttee was taken off it; the right leg felt warm.

October 26. M. C., had lunch one hour before, and had walked outside for some time. The pulse was 94. The feet were put in the bath at 2:22, and in calorimeters at 2:39 p. m. At 2:52 a puttee was put firmly on the right leg and one slackly on the left leg. At 3:16 the puttees were taken off quickly. At 3:32 the feet were taken out of the calorimeters.

The cooling of the calorimeters in twelve minutes was 0.31 C. The volume of the right foot was 1,180 c.c., of the left 1,128 c.c. The water equivalent of the calorimeters with their contents was, right 3,623 c.c., left 3,385 c.c. The rectal temperature was 37.05 C.

If the twenty minute period is analyzed, it is seen that for the first half of it the flow was 6.84 gm. and 6.97 gm. for the two feet,

respectively; and for the second half 6.13 gm. and 6.3 gm. The diminution in the right foot is not due to pressure of the bandage, since it is the same as the diminution in the left. Removal of the puttees was followed by some increase in flow in both feet, but without disturbance of the relation of equality in the two feet present from the beginning of the experiment. The increased flow cannot be interpreted as due to the vasomotor paralysis following the removal of a tight bandage described by Bier. For the puttee on the right leg was not so tight as to occasion the slightest discomfort, and the increased flow was present in the left foot as well as in the right.

TABLE 4

Time	Temperature of Calorimeters		Room Temperature	Time	Temperature of Calorimeters		Room Temperature
	Right	Left			Right	Left	
11:26	30.92	30.78		12:05	32.46	31.99	24.15
11:29	31.00	30.86	25.2	12:07*	32.56	32.08	24.2
11:31	31.07	30.92	25.2	12:09	32.61	32.14	24.2
11:33	31.17	30.98	25.2	12:11	32.68	32.18	
11:35	31.27	31.07	25.1	12:13	32.73	32.23	24.2
11:37	31.37	31.16	24.7	12:15	32.80	32.28	24.25
11:39	31.49	31.26	24.4	12:17	32.88	32.34	
11:41	31.59	31.34		12:19	32.96	32.40	24.2
11:45	31.71	31.43	24.5	12:21	33.00	32.455	
11:47	31.76	31.45	24.4	12:23	33.07	32.51	24.2
11:49	31.81	31.48	24.3	12:25	33.09	32.55	
11:51	31.895	31.55		12:27	33.13	32.59	24.1
11:53	31.96	31.59	24.1	12:29	33.17	32.64	24.1
11:55	32.04	31.65	24.0	12:31	33.19	32.66	
11:57	32.16	31.755	24.0	12:33	33.20	32.68	24.0
11:59	32.22	31.81	24.0	12:35	33.20	32.68	
12:01	32.28	31.85	24.05	12:37	33.12	32.615	
12:03	32.37	31.91	24.1	12:49	32.81	32.31	

* The right leg was comfortable, the left somewhat tired and uncomfortable.

In the experiment shown in Table 3 the procedure was the same as in the last experiment, except that the puttee on the left leg (put on quite slack) was removed some time before the other, in order to see whether the increased loss of heat from the left leg caused any effect on the flow in the right foot. There was, as a matter of fact, a slight diminution in the flow in the left foot, which might be attributed to vasoconstriction due to increased cooling. If this was the cause,

the action extended reflexly to the right limb, the puttee on which had not been disturbed, as the ratio of the flows in the two feet remained unchanged. There was no indication that the pressure of the puttee on the right leg diminished the flow in the right foot.

October 29. M. C., one hour after lunch, put his feet in the bath at 2:20, in the calorimeters at 2:37 p. m. The pulse was 88. At 2:56 a puttee was

TABLE 5

Date	Pulse Rate	Temperature (C.) of				Volume of Foot in C.c.		Heat Given Off in Gm.—Calories		
		Room	Arterial Blood	Calorimeters		Right	Left	Right	Left	No. Min.
				Right	Left					
10/22	90	24.3	36.29	31.37	31.35	1,171	1,128	2,115	1,792	18
		24.1	.....	31.83	31.67	.....	.....	5,170	4,551	40
		24.1	.....	32.36	32.09	.....	.....	2,680	2,530	19
10/26	94	24.2	36.45	31.61	31.60	1,180	1,128	3,695	3,549	10
		24.05	.....	32.52	32.46	.....	.....	2,855	2,825	10
		24.05	.....	32.99	32.94	.....	.....	2,253	2,248	10
		24.1	.....	33.56	33.49	.....	.....	3,478	3,423	14
10/29	88	24.1	36.36	31.92	31.86	1,190	1,133	3,158	2,913	10
		24.25	.....	32.87	32.78	.....	.....	4,720	4,520	17
		24.2	.....	33.56	33.43	.....	.....	2,051	2,027	10
		24.2	.....	34.04	33.92	.....	.....	3,557	3,516	18
11/ 2	80	24.8	36.34	31.38	31.16	1,171	1,142	2,133	1,905	8
		24.3	.....	31.88	31.54	.....	.....	2,007	1,600	10
		24.1	.....	32.36	31.92	.....	.....	3,743	3,290	16
		24.2	.....	32.90	32.37	.....	.....	2,155	1,923	10
		24.1	.....	33.14	32.60	.....	.....	1,610	1,725	12
11/30	100	20.5	36.41	31.19	31.05	1,171	1,142	6,183	4,602	20
		20.6	.....	31.49	31.23	.....	.....	3,073	2,394	10
		20.9	.....	32.19	31.74	.....	.....	2,750	2,450	10
		21.1	.....	32.60	32.10	.....	.....	1,797	1,675	6
		21.2	.....	33.13	32.57	.....	.....	3,952	3,703	18
		21.0	.....	33.53	32.92	.....	.....	1,121	1,064	6

put firmly on the right leg and one slackly on the left leg. At 3:17 the puttee was rapidly taken off the left leg; at 3:29 off the right leg. The feet were taken out of the calorimeters at 3:49.

The cooling of the calorimeters in fourteen minutes was 0.36 C. The volume of the right foot was 1,190 c.c., of the left 1,133 c.c. The water equivalent of the calorimeters with their contents was, right 3,630 c., left 3,588 c.c. The rectal temperature was 36.96 C.

Indeed, with both puttees on, the flow was slightly and equally increased in both feet, probably on account of the heating effect.

In the next experiment to be quoted (Table 4) the puttee was purposely put on the left leg so tightly as to produce a certain amount of discomfort, while it was applied to the right leg with the ordinary, comfortable degree of pressure. The subject was hungry (four and

TABLE 5—(Continued)

Blood Flow in Gm. per Min.		Flow per 100 C.c. of Foot per Min.		Ratio of Flow in 2 Feet	Remarks
Right	Left	Right	Left		
26.53	22.39	2.26	1.98	1:1.14	Before puttee was put on
32.20	27.37	2.75	2.42	1:1.14	Puttee on right leg
39.88	35.23	3.40	3.12	1:1.09	Puttee off
84.82	81.31	7.18	7.20	1:1.00	Before puttees put on; after eating
80.72	78.67	6.84	6.97	1:1.02	Put. R. firm, L. slack (first 10 minutes)
72.35	71.16	6.13	6.30	1:1.03	Put. R. firm, L. slack (next 10 minutes)
95.51	91.78	8.09	8.13	1:1.00	Puttees off
79.03	71.92	6.64	6.34	1:1.05	Before puttees put on; after eating
88.39	82.52	7.42	7.28	1:1.02	Put. R. firm, L. slack
81.39	76.37	6.83	6.78	1:1.01	Puttee off L. leg
94.64	88.94	7.95	7.85	1:1.01	Puttees off both legs
59.73	51.08	5.10	4.47	1:1.14	Before puttees; after eating
50.00	37.03	4.27	3.24	1:1.31	Put. R. firm, L. too tight (first 10 minutes)
65.31	51.69	5.57	4.52	1:1.23	Put. R. firm, L. too tight (next 16 minutes)
69.60	53.82	5.94	4.71	1:1.26	First 10 minutes after puttees removed
46.58	42.70	3.97	3.73	1:1.06	Next 12 minutes after puttees removed
65.80	47.69	5.62	4.17	1:1.34	Before puttees put on
69.39	51.35	5.92	4.49	1:1.31	Last 10 minutes before puttees
72.64	58.51	6.20	5.12	1:1.21	First 10 minutes with puttees
87.34	71.97	7.46	6.30	1:1.18	Next 6 minutes with puttees
74.37	59.52	6.35	5.21	1:1.21	After tightening tapes on R. leg
54.06	42.34	4.61	3.70	1:1.24	After puttees off

one-half hours after breakfast) and the flow in the feet was less than in the experiments shown in Tables 2 and 3. The flow in the two feet was 5.10 gm. and 4.47 gm., respectively, per 100 c.c. per minute for an eight minute period before the application of the bandages (ratio of left to right 1 to 1.14). For a period of twenty-six minutes with the puttees on the flow was 5.13 gm. and 4.04 gm., respectively

(ratio 1 to 1.27). The cutting down of the flow by the improperly applied puttee on the left leg is evident, although the bandage was not put on so tight as to cause an extreme degree of discomfort.

November 2. M. C., four hours after breakfast, put his feet in the bath at 11:07, in the calorimeters at 11:27:30 a. m. At 11:41 puttees were put firmly on both legs, but the left was much tighter and less comfortable than the right. At 12:11 the puttees were rapidly taken off. The feet were taken out of the calorimeters at 12:35.

The cooling of the calorimeters in twelve minutes was, right 0.31 C., left 0.305 C. The volume of the right foot was 1,171 c.c., of the left 1,142 c.c. The water equivalent of the calorimeters with their contents was, right 3,616 c.c., left 3,595 c.c. The pulse was 80. Rectal temperature was 36.96 C.

If the period is analyzed, the deficit in the left foot is seen to be greatest in the first ten minutes (flow in right foot 4.27 gm. per 100 c.c. per minute, in left 3.24 gm., giving a ratio of 1 to 1.31). The flow in the right foot is also diminished somewhat. In the remaining sixteen minutes of the period of application of the puttees the flow increases in both feet, but relatively more in the left, as the venous pressure rises and forces the block (5.57 gm. for right and 4.52 gm. for left foot, ratio 1 to 1.23). Even with the tight bandage on the left leg, the initial flow in the left foot is soon reestablished. This, however, is in a healthy man, whose cutaneous flow is uniformly good. It seems clear enough that in men who habitually suffer from cold feet, and whose foot flow is therefore normally small, the injudicious application of a puttee might easily cause a harmful reduction in the flow which would render the foot more readily susceptible to the effects of cold and wet, of slight injuries and of the passive congestion associated with standing for long periods in one position. On the other hand, so far as can be judged from experiments of such relatively short duration, a properly adjusted puttee not only causes, under normal conditions, no permanent diminution in the foot flow, but may even somewhat increase the flow, probably largely because of its heat conserving property.

In another experiment (that of November 30) different methods of fastening the puttees were investigated. That on the right leg was tied by tapes an inch wide, that on the left leg was fastened smoothly by a safety pin. The tapes caused a somewhat tighter feeling, according to the subject, than the pin, but both legs felt comfortable. After the first sixteen minutes the tapes were made considerably tighter on the right leg, but not uncomfortably so. As will be seen in Table 5, the tightening of the tapes did not produce any diminution in the flow in the right foot as compared with that in the left, although the flow in both was now diminishing, and diminished still more after removal of the puttees. This last decrease in the flow, seen also in the experiment of November 2, may be due to a vasoconstriction associated with

cooling of the limbs after removal of the bandages. However, a terminal vasoconstriction due to the exposure is not uncommonly seen in long experiments on the foot flow when no bandages have been applied.

SUMMARY

It is shown that a puttee applied with the usual degree of pressure on the leg causes no diminution in the blood flow through the foot. When it is put on so tight that some discomfort is produced the flow in the foot is at first reduced.