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Changes in foot volume and capillary fragility during continuous cold exposure and starvation

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Norman, Paul S., Marlin B. Kreider and P. F. Iampietro. *Changes in foot volume and capillary fragility during continuous cold exposure and starvation.* J. Appl. Physiol. 15(2): 261–264. 1960.—The effects of continuous cold exposure (2 wk. at 60°F) and starvation on foot volume and capillary fragility were studied in six men. The experimental period was preceded and followed by 2-week periods (control and recovery) at 80°F and a caloric intake of 2400 cal. Foot volumes decreased 6.1% in the first 5 hours of cold exposure and remained constant for the remainder of the experimental period. Foot volume was also measured after 3 minutes of elevation of the foot and occlusion of the blood supply. This volume decreased less during the experimental than the preceding or following periods. Capillary fragility decreased slowly during the experimental period and increased in the recovery period. On the third day of recovery, foot volumes were larger than at any other time. For the remainder of recovery, foot volume was the same as the control volume, but there was a greater decrease in volume with foot elevation. The results suggest that there was a constriction of all types of blood vessels during the experimental period while in the recovery period there was apparently a simultaneous dilatation of large blood vessels and a constriction of small ones. One subject had a greatly increased volume of one foot associated with pain and redness during early recovery days. These changes may be indicative of early trench foot or capillary damage. Starvation per se appeared to have no effect on foot volume.

Subjects exposed to a cold environment (nude at 60°F) for prolonged periods of time often complained of transient foot pain and tenderness during rewarming (1, 2). The possibility of mild trench foot was considered but was not investigated. Trench foot has been a common occurrence in chronic nonfreezing cold environments (3–5). Edema formation and increased capillary permeability are both found in mild trench foot (6). Capillary changes due to local hypothermia have been demonstrated by Lewis and Love (7) and Willman and Hanlon (8).

Recently the opportunity was afforded to study six men living nude for 2 weeks at 60°F. During this period no food was consumed. Foot volumes and capillary fragility of the dorsum of the foot were measured to ascertain if a pattern simulating mild trench foot was present.

PROCEDURE AND METHODS

Six healthy men, aged 18–27 years, wearing only cotton shorts, lived in a temperature-controlled room for 6 weeks. Their activities were sedentary, e.g. card playing, reading, writing, watching movies and television. The first 2 weeks served as a control period, with room temperature at 80°F, relative humidity 40–50%, wind less than 1 mph. Their diet (2400 cal/day) consisted of an enriched milk drink, buttered toast and coffee. The second 2-week period was the experimental period, with temperature at 60°F, relative humidity 40–50% and wind less than 1 mph. Diet during this period was noncaloric (water ad libitum and black coffee). The conditions during the third 2-week period (recovery period) were the same as those of the control period. In all periods, each subject was allowed one woolen army blanket during the sleeping hours.

Measurements of foot volume were made 16 times during the 6 weeks (four times in control, six in experimental and six in recovery). Volume of the foot was estimated by measuring the water displaced by the foot in a metal boot. Measurements were made with the subject erect and with his weight placed equally on both feet. The amount of water in the boot before immersion of the foot was kept constant. The water was always at room temperature (80°F control and recovery, 60°F experimental period). The lower extremities were kept in a horizontal position for 15 minutes prior to measure-

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ment. The volume of the right foot was measured. The right foot was then supported at an elevation of 18 inches for 3 minutes with the subject supine. With the foot still elevated, a pressure of 200 mm Hg was applied with a tourniquet 3–4 inches below the knee to cause arterial occlusion. The foot volume was again measured with the subject in the erect position and the tourniquet in place.

Capillary fragility was measured by means of a suction petechiometer similar to the apparatus of Kramár (9). The maximal negative pressure of our apparatus was 60 cm Hg. The time required to produce 12 petechiae under the suction cup (i.d. of suction cup 15 mm) was taken as the end point. This varied from 0.5 to 8.0 minutes with the suction constant at 60 cm Hg. Measurements were taken after the men had been supine for at least 15 minutes. Four areas on the medial side of the dorsum of the right foot, over the metatarsal bones, were rotated as the testing site with no site being used more than once in 48 hours.

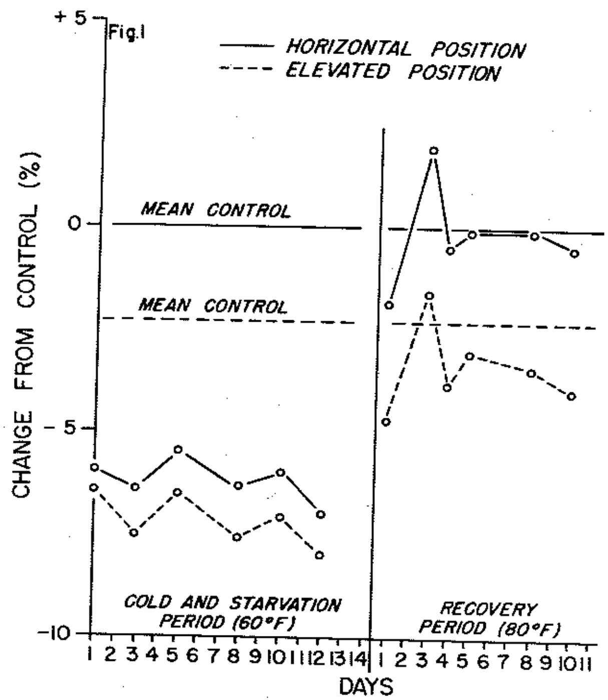
RESULTS

Foot volume. Average foot volume during the control period was 1279 cc. After 5 hours in the cold foot volume was 1200 cc. This represents a decrease, in the cold (fig. 1), of 6.1 %. All the men showed this pattern (range of decrease 3.9 %–7.3 %). Foot volume during the remainder of the cold period remained essentially unchanged after the first 5 hours.

The mean decrease in foot volume with elevation and arterial occlusion was 29 cc (control) 14 cc (experimental) and 41 cc (recovery) periods; the three periods differed significantly from each other. The volume of the foot after elevation and arterial occlusion was less during the experimental period than during control and recovery periods (table 1). The volume during recovery averaged 15 cc lower than the control volume (control, 1250 cc; experimental, 1186 cc; and recovery, 1235 cc).

Foot volume during recovery did not return to control values until 3 days had passed. Five hours after leaving the cold room five of the six subjects' foot volumes were midway between control and experimental values, while the sixth subject had an increase of 44 cc above his highest control value. The right foot of this subject was painful, red and subjectively warm during the first 3 days of recovery. On the third day of recovery, the average foot volume for six subjects was 24 cc above the average for the control days and 29 cc above the average for the remaining recovery values. Foot volume after elevation and occlusion on the third day of recovery was 19 cc greater than any other recovery day. From the fourth recovery day until termination of the study, foot volume of all the men remained unchanged at approximately control values.

Capillary fragility. Capillary fragility on the dorsum of the right foot decreased during the experimental period and rose again during recovery (fig. 2). The mean time to reach the end point (formation of 12 petechiae) was 2.3 minutes in the control, 5.2 minutes in the experimental and 4.2 minutes in the recovery periods. There was marked individual variation in the rate of change of capillary fragility in both the experimental and recovery



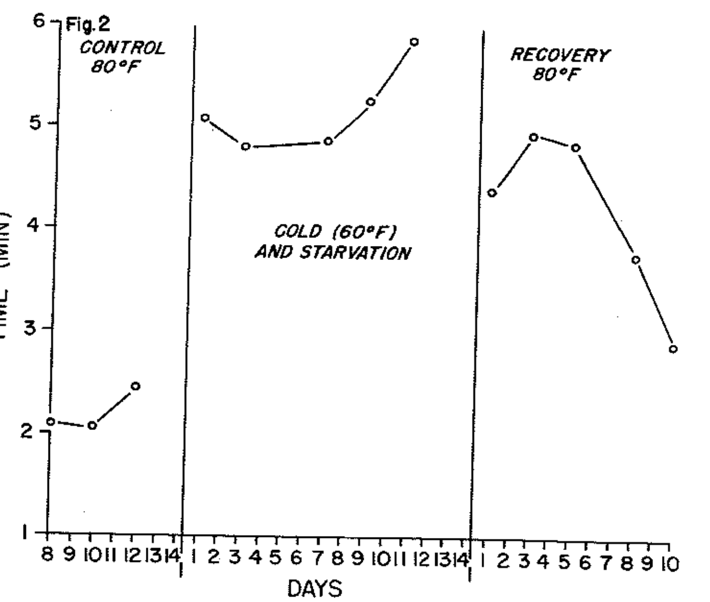


FIG. 1. Per cent change of foot volume of six men during cold-starvation and recovery periods from preceding control period.

FIG. 2. Capillary fragility of six men during control, cold-starvation and recovery periods. *Ordinate* is time in min. required to produce 12 petechiae on dorsum of the right foot.

periods. The end point during recovery never returned to control values. *Subject D*, who had a swollen right foot on the first recovery day, demonstrated marked capillary fragility (12 petechiae present in ½ min. with 60 cm Hg) on this day of recovery. The mean time for the remainder of the group (i.e. excluding *subj. D*) to reach the end point on the first recovery day was 5.15 minutes. *Subject D* had a positive end point in less than 1 minute throughout the recovery period, whereas the mean end point for the other men was 4.8 minutes.

DISCUSSION

No pattern simulating trench foot was found in five of the six subjects although two subjects complained of foot pain and tenderness during the first 2 days of recovery. The sixth subject, *subject D*, however, had the findings of early, mild trench foot.

Foot volume decreased within 5 hours after entering the cold conditions and remained unchanged during the remainder of the cold period. During the early recovery period, foot volume exceeded the control volume and later returned to control values. The smaller, constant foot volume in the experimental period can be explained by a general vascular constriction. Three minutes of elevation caused a further reduction in foot volume, due to a decreased amount of intravascular fluid. A foot elevated for this length of time should lose pooled venous blood and possibly have a decreased arterial inflow, but should not lose any extravascular fluid. Since there was a greater change in foot volume with elevation during control and recovery periods than during the experimental period, a greater amount of blood was probably present in the large vessels during the warm condition. One of the first reactions to cold is peripheral vasoconstriction (5), which would reduce arterial and arteriolar flow to the feet. Wood, Bass and Iampietro (10) found decreased blood flow to the arm as well as venous constriction with exposure at 60°F and no further significant changes as the cold period continued. It is likely that similar changes would occur in the feet thus reducing venous pooling in the feet and producing smaller foot volumes in the cold.

TABLE 1. *Mean Foot Volume of Six Men Following 15 Minutes of Reclining* and 3 Minutes of Foot Elevation†*

Day of Period	Vol., No Occlusion, cc	Vol., Occlusion, cc
	Control	
3	1274	1250
8	1272	1238
10	1281	1253
12	1288	1257
Mean	1279	1250
	Cold	
1	1203	1198
3	1197	1183
5	1209	1196
8	1198	1182
10	1202	1188
12	1191	1177
Mean	1200	1186
	Recovery	
1	1256	1218
3	1303	1257
4	1272	1230
5	1278	1239
8	1275	1235
10	1272	1228
Mean	1276	1235

* Without occlusion. † With occlusion.

Capillary fragility measures the capacity of the capillary wall to resist increased intracapillary pressure or extracapillary suction (11). The capillary walls consist of a single layer of endothelial cells held together by cement substance. Substances passing through the capillary wall must pass either through the endothelial cell or through the cement substance (12). When capillaries constrict, their flat cells might become more rectangular and the cement substance, therefore, might have a greater depth from intracapillary lumen to capillary exterior. Sanders, Ebert and Flory (13) observed capillary contraction as a result of sympathetic stimulation with swelling in the region of the endothelial cell nuclei which occluded the lumen of the vessel. Increased cement substance depth or increased endothelial cell width caused by swelling of the endothelial cell could account for decreased capillary fragility during the cold period.

Foot volume on the third recovery day was greater than at any other time during recovery, but the decrease in volume after elevation and occlusion was essentially the same as any other recovery day. This indicated that the increased volume of the foot on the third day was probably due to an increase in extravascular fluid (edema) rather than to increased volume of blood in the vessels of the foot. This extravascular fluid had disappeared by the fourth recovery day. Since the foot after elevation and arterial occlusion remained smaller during recovery (after the third day) than during control and since capillary fragility increased only slowly in recovery, it is possible that capillary and other small vessel constriction continued into the warm condition. Thus, it is possible that a paradox of dilatation of the large vessels and constriction of the capillaries may exist during recovery.

Three subjects complained of foot pain and tenderness on the first recovery days, but two of these subjects exhibited no objective findings. Another subject, along with the findings of redness, warmth and greatly increased right foot volume, also had markedly increased capillary fragility. This could indicate that in addition to the increase in large vessel blood volume the capillaries had an increased volume and were thinner walled, or that capillary damage occurred during the experimental period. The signs of early trench foot, including increased capillary permeability with extravasation of edema fluid (6), were present in this subject (*subj. D*).

The changes in foot volume during the experimental period were probably a result of exposure to cold and were not influenced by starvation. Thus, the foot attained its smallest volume within 5 hours in the cold and maintained this volume for the 2-week period. At the time of the first measurement in the experimental period only one meal, breakfast, had been omitted. After 14 days of a nonvitamin, noncaloric diet, no further changes in foot volume were noted.

The relative effects of cold and starvation on capillary fragility are more difficult to evaluate. Capillary fragility had decreased markedly by the second day of the experimental period (fig. 2), and then decreased more slowly during the remainder of the period. It would appear that the early, rapid change in capillary fragility was the result of cold exposure and that the later, slower change was the result of starvation or starvation and cold.

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