

The Effects of Bathing with Inorganic Salts and Carbon Dioxide on Body Temperature, Systemic Circulation, and Food Ingestion and Absorption

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炭酸ガス含有無機塩浴の効果 —体温、体循環と食物吸収—

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抄 録

無機塩類と炭酸ガスから構成される入浴剤浴の末梢循環と消化吸収への影響を健常人を対象に検討した。前腕部分浴においては、入浴剤浴が淡水浴と比較して、入浴中、入浴後に皮膚血流が増加した。その血流増加は、濃度依存傾向であった。また、入浴剤での循環動態を検討した結果、淡水浴と比較して、皮膚深部温、皮膚表面温、皮膚血流について、浴後、有意に高値であり、循環改善が認められた。

さらに本入浴剤の食物吸収に及ぼす影響について、健常人に対する有効性を検討した。その結果、入浴剤浴群で、淡水浴群と比較して、食物摂取後入浴時の血糖値およびインスリンの上昇の抑制傾向が示唆された。総蛋白、総コレステロール、中性脂肪、HDLコレステロールおよび尿酸に関しては、各群間での差はみられなかった。

これらの結果から、本入浴剤浴が、循環改善など健康増進につながるものと考えられた。

Key words : inorganic salts, carbon dioxide, circulatory functions, ingestion, glucose

I INTRODUCTION

The beneficial thermal, hydrostatic and floating effects of bathing are renowned worldwide. The thermal effects of bathing cause dilation of blood vessels and increase blood flow, the floating effects improve motor activity, and the hydrostatic effects enhance the circulatory system. These effects of bathing may promote the health of humans. In Japan, many people go to hot springs to relax and for healthcare. These hot springs contain minerals and gases, such as sodium sulfate, sodium bicarbonate, magnesium sulfate and carbon dioxide among others, which are considered to be beneficial to human health. In addition, many bath additives, comprising one or two minerals or gasses found in hot springs, are sold in Japan.

There are many reports about the effects of bath additives such as carbon dioxide⁶⁻⁸⁾, inorganic salts including sodium sulfate¹⁾, magnesium sulfate²⁻⁴⁾ and sodium bicarbonate⁵⁾, crude drugs⁹⁾, and herb extracts¹⁰⁾. There have been a few reports about the effectiveness of combination of different minerals on healthcare¹¹⁻¹³⁾. For example, the thermal effects of sodium sulfate and sodium bicarbonate, and the superoxide dismutase-like activity effects of sodium sulfate and sodium chloride have been reported. By contrast, there have been very few studies on the effectiveness of a combination of minerals and gasses¹⁴⁾.

Recently, lifestyle-related diseases have been on the increase in Japan through the westernization of diet. Lifestyle-related diseases are becoming a major problem; in particular, the number of patients with diabetes has increased dramatically these days. Diabetes is a disorder of metabolism, distribution and absorption of glucose. The resulting increase in glucose causes many metabolic disorders. Arteriosclerosis and poor circulation caused by chronic hyperglycemia can result in necrosis of the leg, among other problems. It is important to control the glucose level in the blood. In its early stages, diabetes is considered to be improved by dietetic therapy and exercise. If bathing with some bath additives can improve systemic circulation and basal metabolism, then it might be able to improve diabetes or other lifestyle-related disorders.

In this study, we have evaluated the effects of bathing with inorganic salts and carbon dioxide on systemic circulation, circulatory functions, food ingestion and absorption in healthy volunteers to clarify the effectiveness of this type of bathing on health promotion and on prevention of lifestyle-related disease.

II SUBJECTS

The study comprised 27 healthy subjects (mean age, 37±1 years; age range, 24 to 51 years). Data from the subjects were used for three analyses as follows. (1) Five healthy volunteers (4 males and 1 female, 39±2 years) were used to examine the effect on peripheral blood flow of immersion of forearm. (2) Ten healthy volunteers (all males, 36±1 years) were used to examine the effect on circulatory functions of whole-body bathing. (3) Twelve healthy volunteers (9 males and 3 females, 37±2 years) were used to examine the effect on food absorption of whole-body bathing. These subjects were divided into four groups with different timing of bathing and food ingestion. In one group, seven healthy volunteers (39±3 years) took food 20 minutes before bathing. In another group, six

Table 1 Subjects of each group in examination

Group	n	Age(mean \pm S.E.)
(1) peripheral blood flow by immersion of forearm	5	39 \pm 2
(2) circulatory functions by whole-body bathing	10	36 \pm 1
(3) food absorption by whole-body bathing	12	37 \pm 2
•bathing after the food ingestion(control)	7(7)	39 \pm 3(36 \pm 3)
•bathing before the food ingestion(control)	6(7)	36 \pm 3(37 \pm 3)
Total	27(23 males, 4 females)	37 \pm 1

healthy volunteers (36 \pm 3 years) took food 10 minutes after bathing (Table 1).

The procedures complied with the 1975 Declaration of Helsinki, as revised in 1983. Informed consent was obtained from all of the subjects in accordance with the ethics rules of the laboratory.

III METHODS

1. Bath additives

The bath additive used in the current study contained magnesium sulfate, sodium sulfate, sodium bicarbonate, organic acid, and a very small amount of fragrance and dye. Carbon dioxide was generated by dissolving the bath additive containing organic acid, sodium carbonate and sodium bicarbonate in water. The bath additive was dissolved in water in a bath tub or container just before each experiment. The dissolution of 30g of bath additive in 200 ℓ of water gave a concentration of carbon dioxide of about 33ppm. The water in which the bath additive was dissolved was defined as inorganic salt and carbon dioxide (ISCD).

2. Methods of measurement of circulation system

The effect of bathing on the peripheral circulation system was studied by two different methods. First, the forearm was immersed in a 25 ℓ container as a simple and easy method by which to measure the effectiveness of the bath additive on blood flow. Second, whole-body bathing was used to measure the effectiveness of bathing on systemic circulation.

3. Measurement of peripheral blood flow by immersion of forearm

Peripheral blood flow was examined in an artificial climate room at 25 \pm 0.5 $^{\circ}$ C and 50 \pm 2% humidity. Volunteers were acclimatized for 1 hour in this artificial climate. After acclimatization, the basal peripheral blood flow of inside of the forearm was measured. The forearm of each volunteer was then soaked in a temperature-controlled 25 ℓ receptacle container, containing 30, 90 or 150g/200 ℓ of the bath additive or plain water as a control, at 39 $^{\circ}$ C. The forearm was removed from the container 10 minutes later. The peripheral blood flow was monitored for 15 minutes thereafter in the artificial climate room. The peripheral blood flow was measured by a laser doppler flow meter (ALF21R, ADVANCE Co. Ltd.).

4. Measurement of circulatory functions by whole-body bathing

Volunteers were acclimatized in the artificial climate room at 25 \pm 0.5 $^{\circ}$ C and 50 \pm 2% humidity for 1 hour before their basal circulatory functions were measured. The volunteers then moved to a second artificial climate room where they took a bath in a sitting position with slightly bent knees at 39 $^{\circ}$ C for 10 minutes. The bath contained either bath additive at 30g/200 ℓ or plain water for the control

group. After the bath, the volunteers wore clothes suitable for measuring circulatory functions and moved back to the first artificial climate room, where they lay on their backs on a bed. All circulation functions were measured in the artificial climate room. The skin core temperature of the forearm, the skin surface temperature of the forearm, and the skin surface temperature of the instep were measured by a temperature monitor device (CTM 205, TERUMO Co. Ltd.). The peripheral blood flow of the palm was measured by a laser doppler flow meter (ALF21R, ADVANCE Co. Ltd.). The blood pressure (BP), heart rate (HR), cardiac output (CO), pressure rate product (PRP) and total peripheral resistance (TPR) were measured by a circulation measurement system (GP-303, PARAMA-TECH Co. Ltd.).

5. Food absorption by whole-body bathing

The effects of whole-body bathing on food absorption were studied by using a calorie-controlled food, MA pochi, 600kcal/375mℓ (CLINICO CO. Ltd.). The test was conducted in an artificial climate room at 25±2°C and 50±10% humidity. Subjects were acclimatized for 1 hour in this artificial climate before taking a bath in a semi-recumbent position at 39°C for 10 minutes. The concentration of the bath additive was 150g/200 ℓ. After the bath, the volunteers wore clothes suitable for measurement. Glucose, insulin, total protein, total cholesterol, triglyceride, HDL cholesterol and uric acid level in the peripheral blood were sampled before food ingestion and at 20-min intervals afterwards until 120 min after food ingestion.

Statistical methods

The data were analyzed using Student's t-test. Differences were considered to be statistically significant at $p < 0.05$.

IV RESULTS

1. Peripheral blood flow in the forearm immersion test (Fig. 1)

The peripheral blood flow increased immediately after forearm immersion. This increase in the blood flow peaked 3 minutes after immersion, and then decreased until 7 minutes. The blood flow increased in a dose-dependent manner, but the peak level of the blood flow induced by 90g/200 ℓ and that induced by 150g/200 ℓ were almost the same. Thereafter, the blood flow increased again to peak at 10 minutes and then decreased. The blood flow increased again after 12 minutes. This third increase in blood flow was not as sharp as during immersion, and was followed by a gradual decrease. This last change in the blood flow occurred in a dose-dependent manner.

Both in and after immersion, the peripheral blood flow rose significantly in the ISCD group as compared with the plain water group. The pattern of change in the blood flow was almost the same in each group.

2. Circulatory functions in whole-body bathing

1) Skin surface temperature of forearm (Fig.2)

The skin surface temperature was higher after ISCD bathing than after plain water bathing. The skin surface temperatures at 10, 20, 30 and 45 minutes after ISCD bathing were significantly higher

than that before bathing. The skin surface temperatures at 10 and 20 minutes after plain water bathing were significantly higher than that before bathing.

2) Skin core temperature (Fig.2)

The skin core temperatures at 20, 30, 45 and 60 minutes after ISCD bathing were significantly higher than those after plain water bathing. The skin core temperatures at 10, 20, 30, 45 and 60 minutes after ISCD bathing were significantly higher than that before bathing. The skin core temperatures at 10, 20, 30, 45 minutes after plain water bathing were significantly higher than that before bathing.

3) Peripheral blood flow (Fig.3)

The peripheral blood flow after ISCD bathing was significantly higher than after plain water

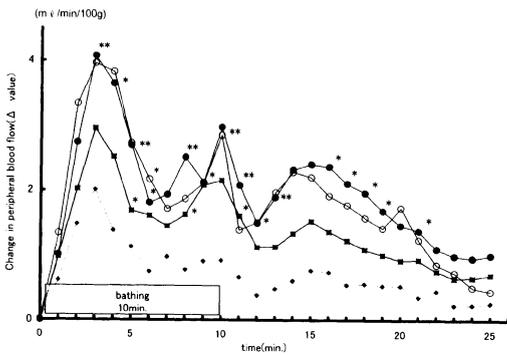


Fig.1 The effects of the bath additive on the peripheral blood flow
 ● 90g/200 l ○ 60g/200 l
 ■ 30g/200 l ◆ Plain Water
 **: p<0.01 vs. Plain Water
 *: p<0.05 vs. Plain Water
 n=5 in each group

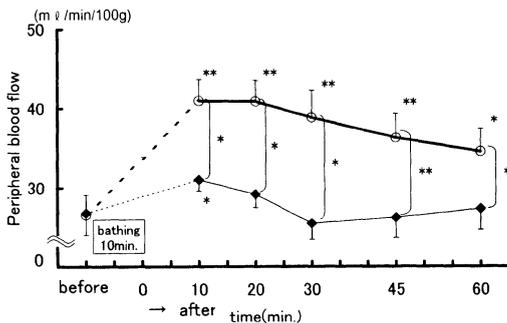


Fig.3 Changes of peripheral blood flow in healthy volunteers
 ○ Bath Additive ◆ Plain Water
 Each value indicates mean±S.E.
 **: p<0.01 *: p<0.05 n=10

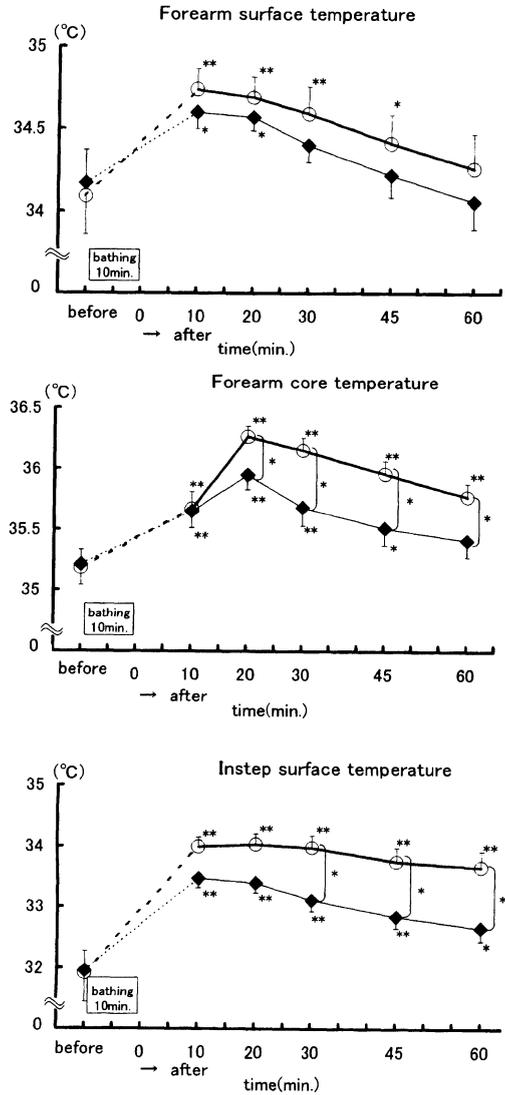


Fig.2 Changes of forearm surface temperature, core temperature and instep surface temperature
 ○ Bath Additive ◆ Plain Water
 Each value indicates mean±S.E.
 **: p<0.01 *: p<0.05 n=10

bathing at 10, 20, 30, 45, and 60 minutes after bathing. The peripheral blood flow was significantly higher at 10, 20, 30, 45, and 60 minutes after ISCD bathing than that before bathing. The peripheral blood flow was significantly higher at 10 minutes after plain water bathing than that before bathing.

4) Skin surface temperature in the instep (Fig.2)

The skin surface temperature was significantly higher after ISCD bathing than after plain water bathing at 30, 45, and 60 minutes after bathing. The skin surface temperature was significantly higher at 10, 20, 30, 45, and 60 minutes after ISCD bathing than before bathing. The skin surface temperature was significantly higher at 10, 20, 30, 45, and 60 minutes after plain water bathing than before bathing.

5) BP,HR,CO,PRP (Fig.4)

Diastolic BP was significantly lower at 10 minutes after ISCD bathing than before bathing. There was no difference between the ISCD and control groups in systolic BP, HR, CO or PRP.

6) TPR (Fig.5)

There was no difference in TPR between the ISCD and plain water groups. TPR was significantly lower at 10, 20, and 30 minutes after ISCD bathing than before bathing. TPR of plain water bathing was significantly higher at 10, 20, and 30 minutes after bathing than before bathing.

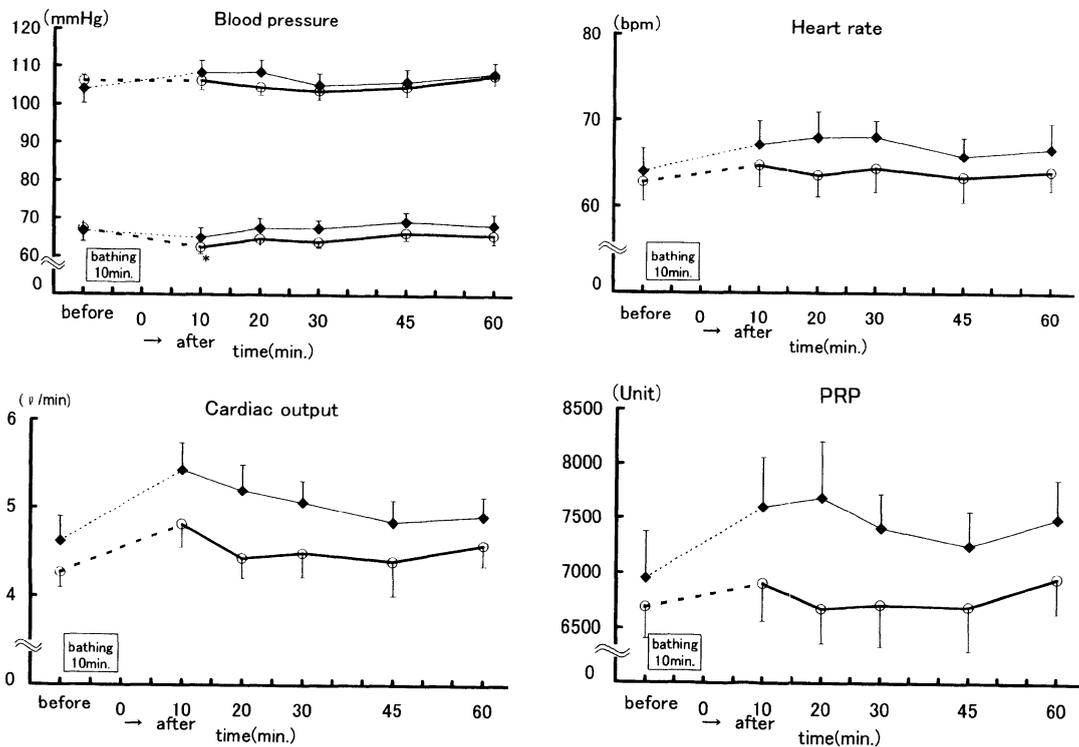


Fig.4 Circulatory changes in healthy volunteers before and after bathing

○ Bath Additive ◆ Plain Water
 Each value indicates mean±S.E. * : p<0.05 n=10

3. Ingestion and Food absorption with ISCD bathing (Fig.6~8)

The effects of ISCD bathing on the blood glucose level were determined in two tests. In the first, the volunteers ingested food before bathing (FBB). In the second, the volunteers ingested food after bathing (FAB). The volunteers in each test were assigned to the plain water and ISCD bathing groups at random. In the FBB test, the blood glucose level in the plain water group reached its highest level at 80 to 100 minutes after ingestion. By contrast, the blood glucose level in the ISCD group remained at about 3/4 of the level in the plain water group (Fig.6). The blood insulin level in the plain water group reached its highest level at 100 minutes after ingestion. By contrast, the blood insulin level in the ISCD group remained half of the level in the plain water group (Fig.6). In the FAB test, the blood glucose and insulin levels were almost the same in the plain water and ISCD groups (Fig.7).

Total cholesterol and total protein levels in the blood did not differ in each group after bathing. The blood triglyceride level in each group increased after bathing. The blood triglyceride level in the ISCD group bathing before ingestion did not increase as much as the plain water bathing group by 60 min (Fig.8). There was no change in HDL cholesterol or uric acid level in the blood before and after bathing, respectively.

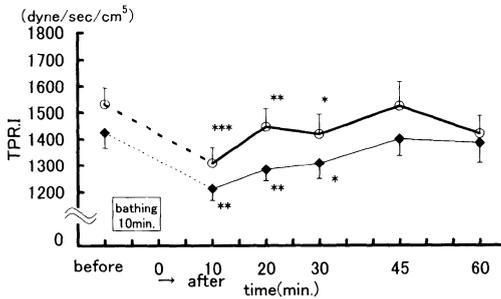


Fig.5 Changes of total peripheral resistance index in healthy volunteers
 —○— Bath Additive —◆— Plain Water
 Each value indicates mean±S.E.
 ***: p<0.005 ** : p<0.01 * : p<0.05 n=10

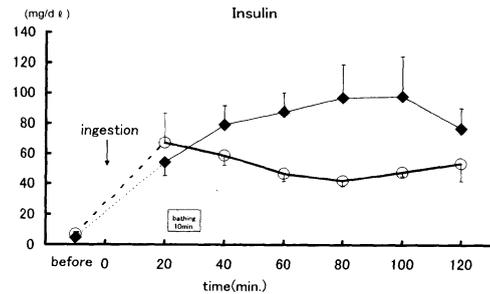
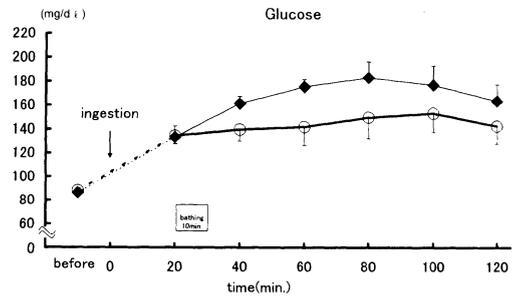


Fig.6 Changes in healthy volunteers before and after bathing
 —○— Bath Additive (n=7) —◆— Plain Water (n=7)
 Each value indicates mean±S.E.

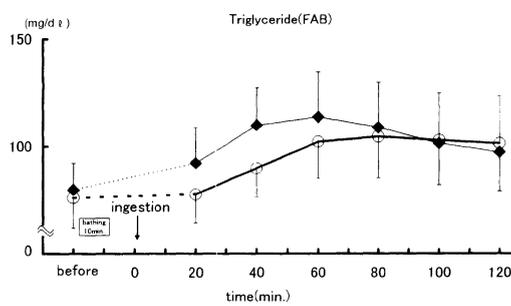
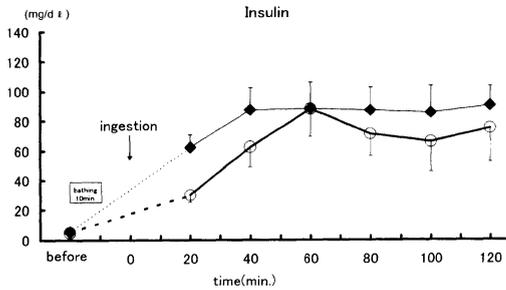
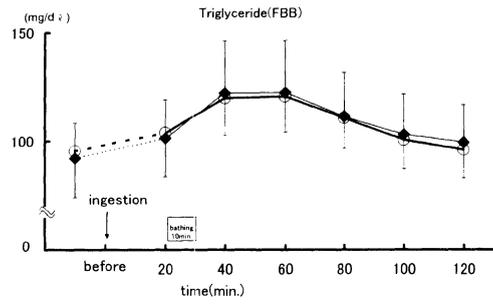
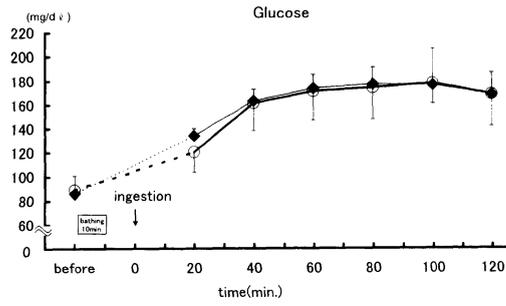


Fig.7 Changes in healthy volunteers before and after bathing
 ○ Bath Additive (n=6) ◆ Plain Water (n=7)
 Each value indicates mean±S.E.

Fig.8 Changes in healthy volunteers before and after bathing
 ○ Bath Additive (FBB : n=6, FAB : n=7)
 ◆ Plain Water (n=7)
 Each value indicates mean±S.E.

V DISCUSSION

Since ancient times, the Japanese have enjoyed hot springs very much. Many people go to hot springs to recover their health in Japan. Such hot springs contain minerals including sodium sulfate, sodium chloride and magnesium sulfate, and gasses like carbon dioxide. These hot springs post notices to people about the beneficial effects of the water. These effects are considered to be dependent on the minerals, ions and/or gasses contained within the hot springs. Many researchers have studied the effectiveness of hot springs in terms of their heat, minerals and gasses and in terms of the environment. Many bath additives have been composed on the basis of such research. Some of them comprise only minerals, whereas others contain materials that generate carbon dioxide when dissolved in water.

In this experiment, we aimed to clarify the effectiveness of a combination of inorganic salts and carbon dioxide on health promotion. Our results suggest that the bath additive used in this study intensifies the thermal effects of bathing. In the forearm immersion test, there were three peaks of blood flow change: the first occurred shortly after the start of immersion; the second occurred just before the end of immersion; the third occurred after the immersion. The first peak rose more sharply than the other peaks. This first rise of the blood flow showed saturation in relation to the concentration of the bath additive, which suggests that the blood vessels are dilated by thermal ef-

fects of the bath additive. Subsequently, the blood flow decreased to half of the peak level. Tanaka has proposed that a change in environmental temperature, such as that caused by bathing, influences the expansion and shrinkage of a blood vessel via the autonomic nervous system²⁵⁾. Iriki suggests that the temperature of the human body is regulated by a feedback control system whereby a plus or minus signal is generated in response to an environmental factor²⁴⁾. Thus, the decrease observed in our study may represent maintenance of homeostasis and feedback control for the transient increase of blood flow.

If so, the second peak may emerge following feedback control of the decrease after the first increase. The third rise in blood flow, which occurred after the immersion, was not so sharp, but it was dose-dependent. This rise was also seen after the plain water immersion. These results suggest that the bath additive may act on a mechanism that controls the blood flow and the extension of blood vessels in accordance with thermal effects.

There have been a few reports on the thermal effects of bathing in sodium and magnesium sulfate on body temperature¹⁻⁴⁾. The characteristic effect of these inorganic salts is to maintain the rise in body temperature longer than plain water after bathing. Our results of whole-body bathing are in keeping with those reports. This suggests that inorganic salts and carbon dioxide work in a similar way. The blood flow after whole-body bathing was maintained for longer than that after forearm immersion, suggesting that the amount of thermal energy may differ in different tests.

There are many reports on the increase in peripheral blood flow that occurs during carbon dioxide bathing^{6,8)}. Carbon dioxide absorbed in the capillaries is drained in due course⁶⁾. Our results indicate that the thermal effects and the rise in the blood flow are maintained even after ISCD whole-body bathing. This suggests that carbon dioxide may be absorbed immediately and act to dilate the blood vessels, and that inorganic salts may maintain this dilation longer than plain water. Although both inorganic salts and carbon dioxide could cause these effects, the extent of the contribution of each component to the circulatory function is not clear.

Recently, Tanaka et al. reported that thermal effects of bathing have an influence on internal organs such as the kidney, liver, stomach, and intestine and on peripheral nerves like the F-Wave¹⁵⁻¹⁷⁾. It has been reported that the blood level of acetaminophen after its direct administration to the small intestine is increased by plain water bathing at 41°C¹⁸⁾. In our study, food absorption, as determined by blood glucose, was lower in ISCD bathing than in plain water bathing, which is inconsistent with the results of Tanaka and others. This discrepancy is considered to be due to the different dosage methods used. In our study, food was dosed orally, which implies that ISCD bathing may affect absorption from the small intestine. Alternatively, if the glucose absorbed is delivered immediately to peripheral organs, then the blood level of glucose would not show an increase. Fuku and others have reported that high inhalation of carbon dioxide after glucose administration promotes a decrease in blood glucose concentration without an increase in insulin in healthy men^{19,20)}. It has also been reported that an increase in blood flow through strong blood vessel expansion caused by carbon dioxide promotes glucose uptake in skeletal muscle²¹⁾. These results suggest that glucose uptake to each organ may be increased by carbon dioxide. In this study, the bath additive used included inor-

ganic salts and materials to generate carbon dioxide. In one sense, the inorganic salts show almost the same effects as carbon dioxide; therefore, the effects on blood glucose level may be due to the combination of inorganic salts and carbon dioxide.

There have been many reports on blood glucose and skin function. In diabetic mice, for example, both the epidermal proliferation and water content in the stratum corneum, without any accompanying impairment in the stratum corneum barrier function, are similar to what is found in aged human skin²²). Hanefeld has pointed out that hyperglycemia is related to the convalescence of type 2 diabetes, myocardial infarction and the total number of deaths²³). These reports suggest that control of the blood glucose level is really important for health promotion. In turn, our results suggest that bathing with inorganic salts and carbon dioxide could be a method of health promotion.

Regarding the lower absorption of glucose from the small intestine following food ingestion associated with ISCD bathing, in the future it will be necessary to study the uptake of blood glucose to muscle and other tissue. In addition, the combined effects of bathing in carbon dioxide or inorganic salts on blood flow increase and thermal maintenance have been studied, but the individual contributions of each remain unclear, representing a future problem that we should examine.

VI CONCLUSION

1. The effects of ISCD immersion of the forearm on the peripheral blood flow of healthy volunteers was measured. Peripheral blood flow tended to increase in a dose-dependent manner after the immersion, indicating that ISCD immersion improves peripheral circulation due to vasodilation.
2. The effects of whole-body ISCD bathing were studied in healthy volunteers. After bathing, the skin core temperature of the forearm, the skin surface temperature of the instep, and peripheral blood flow of the palm were significantly higher with ISCD than with plain water bathing. Furthermore, the skin surface temperature of the forearm was high with ISCD as compared with plain water bathing. Diastolic BP was significantly decreased after ISCD bathing, whereas systolic BP, HR, CO and PRP did not differ before and after ISCD bathing. TPR was significantly decreased after ISCD bathing. These results indicate that ISCD bathing may have beneficial effects on circulatory functions.
3. The influence of bathing on glucose absorption was studied in healthy volunteers. After ingestion, blood glucose and insulin levels after ingestion tended to be suppressed with ISCD as compared with plain water bathing. There was no change in total protein, total cholesterol, triglyceride, HDL cholesterol and uric acid levels in the blood among the ISCD and plain water bathing groups.

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Summary

The effects of bathing with inorganic salts and carbon dioxide (ISCD) on body temperature, systemic circulation, food ingestion and absorption have been studied in healthy volunteers. The peripheral blood flow in the forearm was found to increase in and after immersion of the forearm into a 25 ℓ bathing receptacle containing ISCD, as compared with plain water. The peripheral blood flow tended to increase in a dose-dependent manner with ISCD bathing. The skin core temperature, the skin surface temperature and the peripheral blood flow were significantly higher after ISCD bathing than after plain water bathing. The influences of ISCD bathing on food ingestion and absorption were also studied in healthy volunteers. Blood glucose and insulin levels after food ingestion tended to be suppressed by ISCD bathing as compared with plain water bathing. There was no difference between ISCD and plain water bathing in total protein, total cholesterol, triglyceride, HDL cholesterol, and uric acid levels in the blood. These results suggest that ISCD bathing may contribute to the promotion of human health.