Carbon Dioxide Bath (Carbon Dioxide Spring)

by

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Balneotherapy using naturally occurring carbonated water (more precisely, a carbon dioxide-containing spring) is at once the most traditional of therapeutic methods and also the most thoroughly studied technique in the field of applied balneotherapeutics. Sources of springs called "carbon dioxide springs" have since ancient times been used not only as spas for bathing but also for drinking. As H.D. Hentschel writes in his review of the history of carbonated water, the major direct effects had already been repeatedly observed by early spa physicians. Bode of Bad Nauheim noted a "congested, velvety, reddened skin" (1845); Piderit (1836) and Beneke (1859) described a sensation of warmth in CO_2 baths and flushing of the skin in the bathed areas of the body; and in 1911 Goldscheider discussed the possibility that flushing of the skin arising from sensory stimulation by carbon dioxide may be due to vasomotion. In absorption experiments conducted by Hediger (1928), it was first demonstrated that CO_2 is absorbed by passing through intact skin, although there were still many errors in the quantitative measurements taken at the time.

Definitions

In the "definition" shown in Table 1, a carbon dioxide spring is a spring that issues forth naturally or has been dug, and that contains as the minimum critical concentration 1,000 mg/kg of free CO_2. The minimum critical concentration for drinking water springs differs in German-speaking countries (in Austria, the minimum for drinking water springs is 250 mg; whereas in Switzerland, the minimum for both drinking water springs and spas is 250 mg). At thermal carbon dioxide spas, the water temperature must exceed 20°C. A number of other items concerning minerals (e.g., brine) have also been added in Table 1.

Carbon dioxide originates primarily from volcanoes; that is, quiescent volcanoes. Accordingly, the presence of carbon dioxide springs is limited to geologically old volcanic zones. For this reason, most springs containing CO_2 are "juvenile" and have not yet been brought to light. Occasionally, the decomposition of carbonates when organic matter breaks down results in the production of carbon dioxide. In addition, carbon dioxide is sometimes emitted as a "gas spring" (carbon dioxide fumarole).

Pharmacology of Carbon Dioxide in Balneotherapy

At rest, the human body produces and exhales about 250 mL of CO_2 per minute [6]. In a full bath, depending on concentration, method of measurement and temperature, from 10 to over 80 mL/min/m^2, and on average 30 mL/min/m^2, of CO_2 (equivalent to 1.8 to 4.5 L/h) is absorbed through the skin's surface. This corresponds to from 10 to 12% of the amount of CO_2 to which the body is exposed during this time. Thus, carbon dioxide is absorbed by the body 100 times more powerfully than water [12].

Table 1. Critical concentrations in carbon dioxide springs (from "Definitions")

b) Water containing particularly effective ingredients. Contents of effective ingredients must exceed the levels indicated below.

1. Iron-containing water	20 mg/kg iron
2. Iodine-containing water	1 mg/kg iodine
3. Sulfur-containing water	1 mg/kg sulfides and sulfur (S)
4. Radon-containing water	18 nCi/kg
5. Carbonated water or carbon dioxide spring	1,000 mg/kg free CO_2
6. Fluoride-containing water	1 mg/kg fluorides

c) Thermal springs: water having a natural temperature of at least 20°C

d) All values at a place used must attain or exceed the minimum values (a to c).

The CO_2 additionally taken in by the body from the spa bath is rapidly exhaled, so no change is apparent in the blood concentration of CO_2. Local pH changes occur in the region of the capillaries that have absorbed CO_2, promoting hemoglobin dissociation, from which even stronger oxygen supply (the Bohr effect) to the affected tissue can arise [12].

Direct Effects of Carbon Dioxide Bath

Two effects are observed that leave a strong impression on the patient. These are the countless water bubbles on the skin's surface and the flushed color of the skin (which can be clearly distinguished from the portions of the body not immersed in the CO_2 bath by a thin ischemic border). The water bubbles are innumerable carbonated water bubbles (Fig. 1) which cling to the skin in the manner of fuzz, and are sometimes referred to as "gas brushes." At one time it was thought, incorrectly, that these water bubbles insulate the body from cold water, thus accounting for the apparent warmth of the CO_2 spring for its temperature.

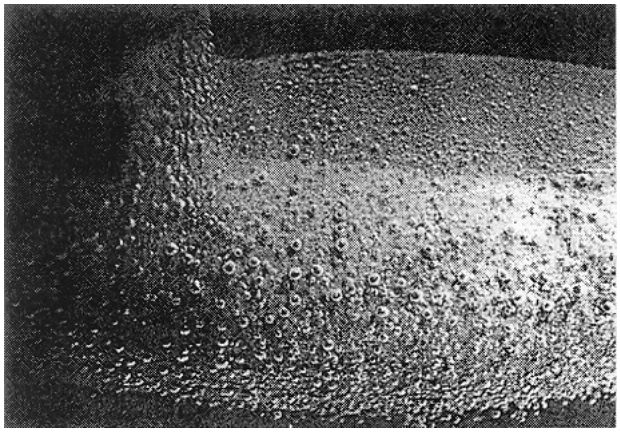

Fig. 1. CO_2 bubbles on forearm immersed in a carbon dioxide bath.

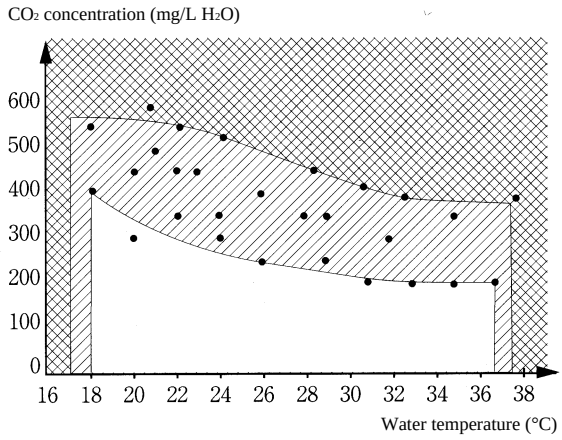

Fig. 2. Relationship between flushing of skin in carbon dioxide bath with free CO_2 concentration and water temperature.
• = flushing of skin visually confirmed; hatched region = flushing of "sensitive" skin; cross-hatched region = constant flushing of skin.
Vertical boundary lines in cold and warm regions indicate flushing of skin unrelated to CO_2 (due to temperature influence) was observed from this area [9].

Flushing of the skin (Fig. 2) in the carbon dioxide bath is already observed at a CO_2 concentration of 300 to 400 mg/L, and is temperature dependent. This effect is caused by dilation of the precapillary arterioles and capillaries. According to a study by Schnizer and Erdl [13], CO_2 bath application promotes spontaneous vascular changes ("vasomotion") in the blood vessels of the skin (Fig. 3). Capillary dilation causes a clear and sustained decrease in capillary resistance and lowering of the blood pressure. Decreases in the adrenaline and noradrenaline values are believed to take part in this effect [6–8]. The temperature sensed in a CO_2 bath at temperatures below the insensible temperature in fresh water (about 35°C) is affected by inhibition of the cold receptors in the skin and stimulation of the warmth receptors, and decreases as a result to about 33°C. In other words, fresh water feels cold at a water temperature of 33°C, whereas a CO_2 bath does not feel cold at the same temperature.

Thus, in a 33°C CO_2 bath, the body becomes slightly but significantly hypothermic. This is accompanied by a decrease in oxygen consumption (Fig. 4). Clear bradycardia is apparent. As Beneke states in his major work on the Nauheim carbon dioxide spas, "The direct effects of a simple carbon dioxide bath bring about clear decreases in both the heart rate and respiration rate."

Overall, dramatic changes occur in the entire circulatory system in the form of a low cardiac load under economic (trophotropic) conditions. In particular, alleviation in the blood pressure gives rise to the effect formerly known as the "heart exercise time" (an expression which is not altogether incorrect). In addition, a direct effect that has been demonstrated in disorders of the peripheral arterial circulation is an improvement in the flow of blood due to a

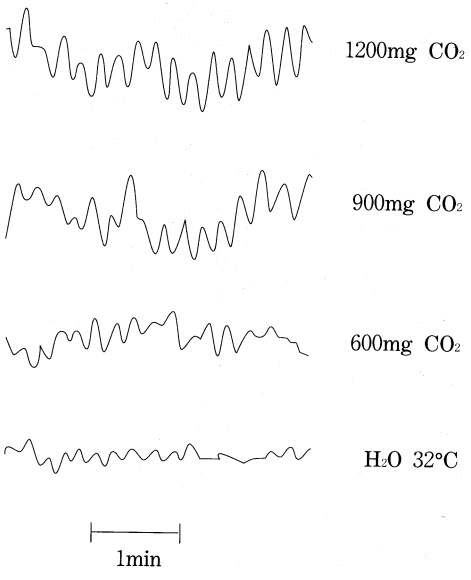

Fig. 3. CO_2 concentration and vasomotor oscillation (actual recordings) [13].

rise in the elasticity of red blood cells that had been depressed in the affected areas. In animal experiments, the application of a CO_2 bath has an effect on experimentally induced inflammation. It has been shown that carbonated water by itself often aggravates inflammation, but that the addition of 3% of NaCl provides an anti-inflammatory effect. This suggests that one must always keep in mind the overall picture concerning the chemical constituents in a therapeutic spring. The same probably applies as well to the distinct effects by CO_2 baths against external injuries such as necrosis and bedsores demonstrated by Gadomski [6].

To summarize, a water bath with CO_2-enriched water triggers many topical changes in the skin and basic modifications in the overall circulation (Table 2). This provides a reliable scientific basis for the use of CO_2 balneotherapy.

Table 2. Direct Effects of Carbon Dioxide Bath

Primary Effects of CO_2 Bath on the Skin:

1. CO_2 bubbles cling to skin.
2. CO_2 diffusion through the skin (not from the gas bubbles). Influencing factors:
   - partial pressure gradient
   - blood flow
   - skin properties
3. CO_2 absorption (10–80 mL CO_2/min; average of 30 mL/min/m^2 body surface area, corresponding to about 1.8–4.5 L/h) (= 10% of amount of CO_2 produced by body in the same time).
4. Rapid transport of absorbed CO_2.

Secondary Direct Effects of CO_2 Bath:

1. Flushing of the skin, presence of distinct ischemic boundary line (at and above 300–500 mg CO_2/L).
2. Dilation of precapillary arterioles and increase in capillaries through which blood is flowing.
3. Promotion of blood flow through capillaries.
4. Increase in amplitude of spontaneous blow flow fluctuations (“vasomotion”).
5. Inhibition of cold receptors and stimulation of warmth receptors, thereby lowering the intermediate temperature from 35°C (fresh water) to 32–33°C (CO_2 water).
6. In a full bath at 32–33°C, the core body temperature decreases 0.5–1.0°C.
7. Changes in circulatory state:
   - decrease in capillary resistance
   - “automatic transfusion to peripheral areas of body”
   - decrease in blood pressure
   - bradycardia

Results: Low-volume load (HMV increase does not exceed 30 to 50%) under economic (trophotropic) conditions of mild hypothermia.

Serial Application:

Adaptive changes in circulatory system over a prolonged period of time.

Table 3. Major effects of drinking carbonated water.

1. Congestion of gastric mucosa.
2. Promotes resorption (such as of CO_2, alcohol, Ca^{++}, Mg^{++}, and aspirin)
3. Depending on state of individual, increases respiration rate and excites central nervous system.
4. Promotes gastric secretion and gastric activity.

Indirect Effects of CO_2 on Gastric Mucosa

The ingestion of carbonated spring water has long been known to stimulate the secretion of gastric acid (Fig. 5). However, there are also other effects on the gastrointestinal tract (Table 3). The appetite-improving effect of carbon dioxide is not the only reason drinking carbonated water is so popular. In particular, the effects of carbon dioxide on

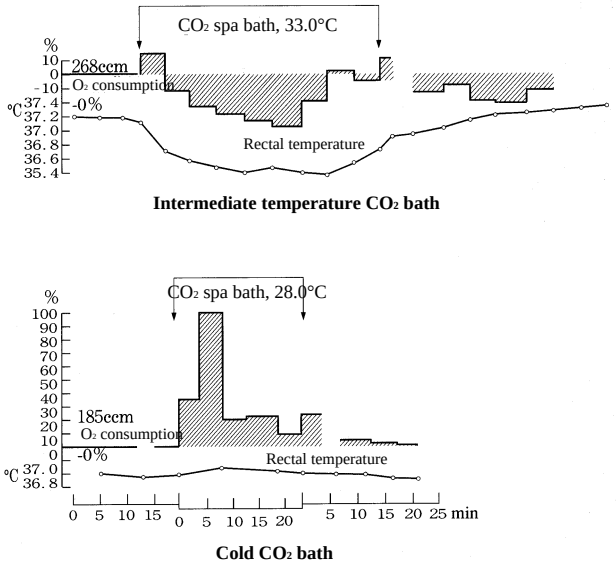

Fig. 4. Changes in rectal temperature and oxygen consumption in intermediate temperature and cold carbon dioxide baths (from Gollwitzer-Meier) [16].

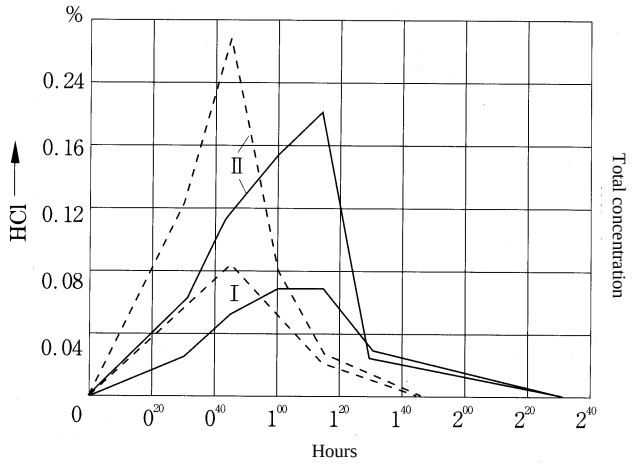

Fig. 5. Effects of carbon dioxide on gastric acid secretion.
— Water - - - CO_2 water
I: Free HCl II: Total acidity [16]

promoting absorption by the gastric mucosa must not be disregarded.

Long-Term Effects of CO_2 Baths

The direct effects of CO_2 baths are utilized for therapeutic ends. In addition, the pharmacological effects of carbon dioxide have been studied and are well documented. However, the sustained long-term effects that are desired can be obtained only through serial applications, and so it is such serial application that determines the ultimate effectiveness of CO_2 baths. These long-term effects are not merely the sum of the individual effects. Rather, they are brought about by fundamental changes in the autonomic nervous system in stimulation, response and adaptation therapy [2,10]. There are instances where trophotropic economic changes in the autonomic state trigger a temporary aggravation in the patient's state (cure crisis) with the passage of time [10] (Fig. 6: CO_2 baths 4–7).

Carbon Dioxide Gas Bath

The carbon dioxide serving as a natural remedy which is closely associated with a local region is not obtained only as a solution in water, but can also be obtained in the form of a true gas spring (carbon dioxide fumarole) that either occurs naturally or has been dug. The direct action of a carbon dioxide gas spring is almost the same as that of a CO_2 water bath, the only difference being that flushing of the skin occurs at a higher temperature (Fig. 7). CO_2 absorption is promoted by wetting the CO_2 gas with a jet of water vapor. However, in at least some patients, this type of

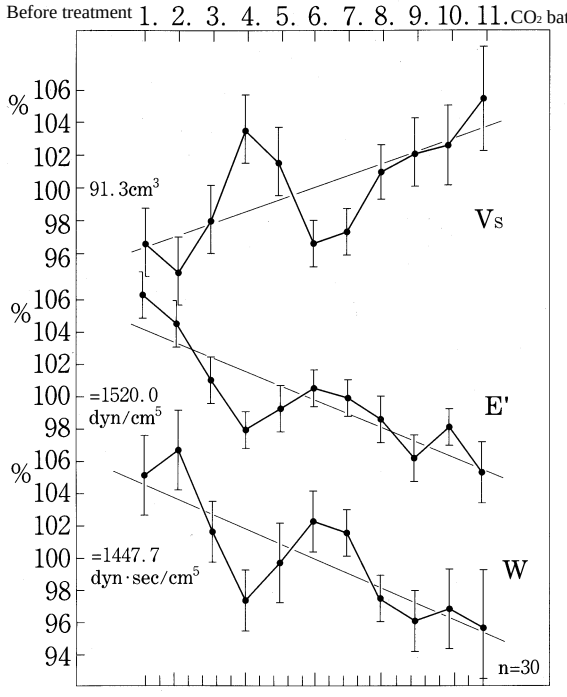

Fig. 6. Changes in stroke volume (Vs), arteriolar elasticity coefficient (E') and peripheral vascular resistance (W) during CO_2 balneotherapy [10].

warm, high-humidity state will produce an increase in the cardiac load despite the diminished hydrostatic pressure.

Artificial Carbon Dioxide Bath

According to the definition of a natural remedy as being closely associated to a natural region and/or a custom of the region, treatment using artificially produced carbonated water cannot rightly be called balneotherapy in the traditional sense of the word. However, through very careful technical preparation (from sodium carbonate and other salts), it should be possible without question to increase the carbon dioxide concentration within bath water to a level which exhibits the same direct effects as natural carbonated water. While some of the effects of a traditional carbon dioxide bath cure can be duplicated in this way, because the treatment lacks in certain respects, it would probably not be feasible to use it in place of an overall combined curative regimen.

Indications for CO_2 Baths

Table 4 presents the major indications for which CO_2 baths are currently recognized as effective. In addition, CO_2

Table 4. Major Indicators for CO_2 Balneotherapy

1. Hypertension, especially borderline hypertension
2. Arteriolar occlusion, Stages I and II
3. Functional arteriolar blood flow disorders
4. Microcirculatory disorders
5. Functional disorders of the heart

Indications for CO_2 gas bath:

Delayed wound healing, topical blood flow disorders, CO_2 therapy indications for which water baths are contraindicated.

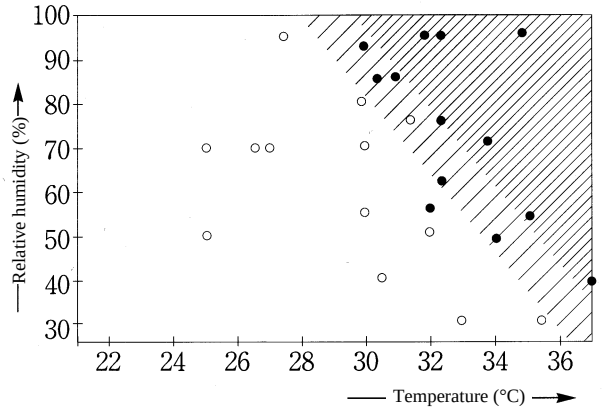

Fig. 7. Relationship of flushing of skin, temperature and relative humidity in CO_2 gas bath (at least 80 vol % CO_2; 15 minutes).
• = flushing of skin; o = no flushing of skin
Densely hatched region indicates constant appearance of flushed skin. Flushing of skin does not arise in an air bath under the same conditions [9].

balneotherapy is used also in functional disorders of the heart, rheumatism (especially in combination with brine and other minerals), and many disorders in autonomic function and regulation. In addition, cold CO_2 baths are regarded as effective for venous blood flow disorders. Indications for CO_2 gas baths include, in addition to the above, intractable external injuries, ulcers, and bedsores. In cases where water baths are contraindicated, it is used as well in classical indications for carbonated water baths. Use in the treatment of coronary disease, NYHA stage I and stage II heart failure, rehabilitation following heart failure (recognized as an indication in the field of combined therapy within former East Germany and Eastern European countries) is still under debate [7].

Contraindications and Precautions for CO_2 Balneotherapy

The various types of decompensation, such as acute pyretic diseases, consumptive diseases and ulcers, for which immersion full baths are contraindicated on account of the effects of immersion are generally contraindicated for balneotherapy practiced in various localities. In addition, contraindications specific to CO_2 balneotherapy include severe hypertension, new cardiac infarctions, aortic and mitral valve stenosis, severe congenital heart failure, cor pulmonale, bronchopulmonary diseases accompanied by hypercapnia, and acute inflammatory vascular diseases. CO_2 balneotherapy is also contraindicated in severe cerebrovascular disorders. When a CO_2 spring source is used in a warm bath, treatment must be safely carried out in such as way as to keep people from inhaling a large amount of CO_2. Water surface measurements at CO_2 spas have shown that 2–4%, and sometimes even higher levels, of CO_2 are present in the air. The patient should be instructed to avoid bringing the nose or mouth any closer than necessary to the surface of the water and to avoid undue exertion while in a CO_2 bath. Even with such precautions, central nervous system symptoms (hypertension, cerebral hypoxia syndrome) will occasionally appear.

To summarize, systematic and skilled balneotherapy utilizing carbonated water, which has been practiced for more than 120 years, has in recent years become solidly grounded in the natural sciences, particularly with respect to its use in the treatment of cardiac and peripheral vascular disorders. No natural remedies can make use of such a broad and diverse base of knowledge as carbon dioxide baths. A number of earlier indications have become outdated and are no longer useful with the development of modern cardiology. Yet balneotherapy which applies carbon dioxide baths for indications in which it is regarded even today as effective is sometimes important and effective for carrying out a treatment program over the course of a lifetime, and effects desirable for treatment continue even beyond the period of balneotherapy. F.W. Beneke, who had not yet acknowledged the carbon dioxide in the carbon dioxide spas at Nauheim as being an effective factor in the cardiovascular effects of treatment, nonetheless made the following statement. “I have never hesitated to allow heart disease patients suffering from rheumatism to bathe in the spas. I believe that bathing for such patients is not without meaning.”

It is my hope that balneotherapy which is being carefully studied in this way will once again become widely used in combined therapy programs, rehabilitation programs, and preventive care programs conducted in various places as cures.

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