Balneotherapy with the Use of Radon–Sulphide Water: The Mechanisms of Therapeutic Effect

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Abstract: Despite its enormous therapeutic potential, spa treatment is not always properly perceived, hence the numerous attempts to assess its effectiveness. In the world literature, there are few reports on therapy using sulphur- and radon-containing therapeutic waters. In countries with a long tradition of balneotherapy, activity in this field of medicine is evident. Undoubtedly, the interest in balneotherapy results also from natural resources used in spa medicine, which, as geological and balneochemical research shows, are enormous in Poland. A particular example of the occurrence of radon–sulphide waters, rare on the European scale, is the Przerzeczyn-Zdrój health resort. The mechanism of action of therapeutic waters is not fully explored, but their effectiveness in therapy is confirmed by many authors. It is believed to be an effect of combined action of many factors, the most important of which are thermal, mechanical, and chemical.

Keywords: balneotherapy; radon–sulphide water; medical water

1. Introduction

The distribution of therapeutic waters in Poland shows a significant preference for southern areas, which is a consequence of the geological structure. In the area of the pre-Sudetes bloc, therapeutic waters are exploited, among others in the Przerzeczyn-Zdrój health resort, where weakly mineralised sulphide–hydrogen and radon waters with mineralisation of 0.4 g/dm

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 are found in Quaternary sediments (Pleistocene and Holocene) [1,2].

Przerzeczyn-Zdrój is located in the Lower Silesian Voivodship, Dzierżoniów County, in the Sudetes Foreland, at an altitude of 242 m above sea level. It lies 4 km south of Niemcza and 56 km from Wrocław in the Ślęza River valley.

The contents of particular components characteristic for the Przerzeczyn-Zdrój therapeutic waters are within the limits of fluctuations observed during long-term research presented in Table 1.

As a result of drilling at the depth of 77 and 150 m in this small health resort, specific sulphide–hydrogen waters with a low radon content of 1.05–2.4 nCi/L, temperature of 11–12 °C, and total mineralisation of 418–480 mg/L, with a deposit capacity of 7 m

3/h, were discovered. Waters of such composition are unique not only in Poland but also in Europe.

From the balneological point of view, therapeutic waters are defined as waters that are bacteriologically and chemically uncontaminated, show little variation of chemical composition and physical features, and exhibit therapeutic effects documented by clinical trials. Therapeutic waters include only some mineral waters; therefore, not every mineral water is therapeutic, and its therapeutic properties are determined by the type and concentration of active biochemical components. In Polish balneology and hydrogeology, the
classification of waters regarded as therapeutic is based on two main criteria, i.e., anion and cation composition and pharmacodynamic and thermal properties [3,4]. Therapeutic waters must contain at least 1000 mg of solid mineral, organic, and gaseous components dissolved in one litre. The type of the therapeutic water depends on the type and amount of these components present in the area of the spring. The degree of saturation of the water with mineral components is influenced by the size of the area and the time and amount of water passing through the area.

Table 1. Results of physicochemical tests performed on 24 April 2008 at the therapeutic water springs and in mineral spring spa (MSP) (own material).

| No. | Sample Location | Water Temp. in °C | pH | H₂S mg | HCO₃ mg | Rn nCi | Rn Bq |
|-----|-----------------|--------------------|----|--------|--------|--------|--------|
| 1.  | Well no. II     | 12.0               | 7.62 | 1.96   | 263.2  | 2.21   | 81.8   |
| 2.  | Well no. IX     | 12.0               | 7.72 | 1.70   | 289.6  | 1.71   | 63.3   |
| 3.  | MSP tub         | 16.0               | 7.65 | 1.87   | 277.9  | 2.20   | 81.4   |

The solubility of the components of the therapeutic water increases with increasing temperature, pressure, acidity, and carbon dioxide saturation. Radon–sulphide therapeutic water containing calcium and magnesium sulphides can be used for all balneological procedures. Tub baths and whirlpool baths use radon–sulphide water. Full baths and half-baths are performed at the temperature of 35–37 °C for an average treatment time of 10–20 min. The number of treatments varies from 8 to 10, and their frequency is ordered by a physician taking into consideration indications and contraindications to the therapy. Radon–sulphur waters are widely used in the treatment of rheumatic, orthopaedic, neurological, and dermatological diseases.

2. The Mechanism of the Therapeutic Effect of Radon–Sulphide Water

The mechanism of action of therapeutic waters has not been fully explored; however, their effectiveness in therapy is confirmed by many authors. It is believed that it is the result of combined action of many factors, the most important of which are thermal, mechanical, and chemical.

Mechanical effects of therapeutic baths include reduction of muscle tension, improvement of joint mobility, and pain relief. Joint oedema is also reduced by increasing sodium excretion and stimulating diuresis. Such changes were observed, among others, in patients with rheumatoid arthritis [5].

The thermal effect of therapeutic baths is characterised by an increase in the secretion of hormones and various types of active proteins. Thermotherapy reduces pain by increasing the serum concentration of endorphins and activates the secretion of cortisol and ACTH (adrenocorticotropic hormone). Moreover, a decrease in the level of immunoglobulins in the plasma, a rheumatoid factor, an increase in erythropoietin activity, and iron activity were also observed [6,7]. Heat increases the elasticity of tissues, i.e., tendons, ligaments, and joint capsules, thus increasing the range of motion in the affected joints and spine.

The chemical effect depends on the chemical composition of the therapeutic water. The sulphur ions and radon activity of the water play a key role in the therapeutic effect of radon–sulphide water. Sulphur is an electronegative acid-forming element that occurs in many forms and in various concentrations. In the presence of oxygen, it shows a high reducing power, which leads to the formation of its various products. This is also the reason why water containing sulphur compounds is highly unstable, especially when mixed with air. Waters containing sulphur, which have been recognised as therapeutic, must contain at least 1.0 mg/dm³ of iodometrically determined sulphur. Therapeutic waters predominantly contain sulphides, i.e., compounds of sulphur with metals. In the process of slow oxidation, these compounds pass through sulphur to the sulphate form.
Sulphide waters contain much less total sulphur compared to sulphate waters, but they contain sulphur at lower levels of oxidation, especially divalent sulphur, which is the most biologically active [8].

During a bath with sulphur content, erythema appears on the submerged part of the body and lasts from a few minutes to several hours. Dilation of most capillaries under the influence of histamine-like substances released in the skin by sulphur causes the transfer of significant amounts of blood into the skin, which also reduces blood pressure in people with normal and high blood pressure. The fragility of blood vessels is also reduced. Sulphide therapeutic water containing calcium and magnesium has an antiallergic, desensitising, antifungal, and antiparasitic effect, and it enhances immunity due to the increased production of antibodies.

In diseases with an increased concentration of uric acid in the blood serum, e.g., rheumatic diseases, degenerative joint and spine diseases, and gout, uric acid concentration decreases after a few baths. Under the influence of sulphur, minor contractures are relaxed, muscle and joint stiffness and pain are reduced, the range of joint movement is increased, and overall mobility is improved. With a series of baths, sulphur, calcium, and magnesium compounds enter the body and partially supplement the existing deficiencies. Waters with sulphur content are used both in drinking and bathing treatment. One of the main indications for the use of sulphur waters are degenerative changes in the joints and spine, which are accompanied by pain. It is believed that the sulphur introduced into the body during the treatment is used for the synthesis of chondroitin sulphuric acid, which is a component of articular cartilage. Moreover, sulphur is known to be part of the proteoglycans of cartilage, bone, and granulation tissue [9].

Sulphur in therapeutic waters is usually present in the form of sulphide and hydrosulphide ions as well as hydrogen sulphide. Depending on the content of hydrogen sulphide, we distinguish waters with low (<50 mg/dm$^3$), medium (50–100 mg/dm$^3$), and high (>100 mg/dm$^3$) concentration of the gas. Sulphur ions penetrate the body through the skin mainly in the form of hydrogen sulphide, thiosulphate, or colloidal sulphur. Hydrogen sulphide penetrates the skin faster than oxygen. In the skin, it is converted into polysulphides, which pass into the blood and then quickly decompose in the tissues into hydrogen sulphide and elemental sulphur. Hydrogen sulphide penetrates the skin faster than oxygen. In the skin, it is converted into polysulphides, which pass into the blood and then quickly decompose in the tissues into hydrogen sulphide and elemental sulphur. It is excreted from the body with the urine and—in the unchanged form—through the lungs.

During bathing, in adults, the absorption of sulphur through the skin is relatively low (about 40 mg in one bath), and the absorption is proportional to its content in the water and the surface of the skin immersed in it. However, in children, this permeability is relatively high. Hydrogen sulphide is particularly well absorbed during bathing, the content of which in the therapeutic water during the treatment itself can be reduced by half, not only due to volatilisation. It was also found that during a bath, hydrogen sulphide penetrates not only through the skin but also through the mucosa of the bronchi, gastrointestinal tract, and the genital tract [9]. Drinking treatment allows for greater sulphur absorption. Studies have shown a rapid absorption of sulphur into the cells. After 20 min, its levels were found to increase in the articular cartilage, bone tissue, vascular wall, and intestinal mucosa. This form of therapy improves absorption and secretion in the intestines, improves gastrointestinal motility and carbohydrate–fat metabolism, and has chologenic, cholepoietic, anti-inflammatory, and desensitising effects [10].

It was found that divalent sulphur penetrating the skin influences immune reactions by inhibiting Langerhans cells and destroys reactive oxygen species (ROS). Sulphur absorbed during a bath inhibits the inflammatory reaction by removing ROS [11]. This mechanism of action probably determines the effective spa therapy of allergic skin diseases and psoriasis [12,13]. This was confirmed by the studies of Agishi et al. They showed the clinical effectiveness of sulphur hot bath therapy in the treatment of atopic dermatitis [14].

Isotopic studies revealed the presence of absorbed sulphur in many tissues, especially the connective tissue, bone tissue, articular cartilage, and in the joint itself. It is estimated
that a total of 58 mg of sulphur may be absorbed during a bath, taking into account all absorption routes [15].

Bathing in water with sulphur content is also used in the treatment of fibromyalgia [16]. It was found that in the course of a two-week therapy, there was a decrease in pain and other symptoms of the disease as well as an improvement in the assessment of quality of life parameters [17,18]. Sulphur is also involved in the synthesis of nucleic acids, it is part of the organic combinations of proteins and enzymes: oxydases, reductases, hydrolases, and transferases. It is particularly necessary in the synthesis of glutathione, which is indirectly involved in the processes of removing or neutralising ROS, as well as necessary for proper cellular metabolism. Sulphur is built into methionine and cysteine, and together with its oxidised form -S-S cystine, it is responsible for the formation of the active oxido-reduction centre of glutathione [19].

In their research, Bugajski and Solecki confirmed the effect of sulphide and hydrogen sulphide water from Busko-Zdroj on the activity of the antioxidant system in patients with rheumatoid arthritis and degenerative spine and joint disease. They observed an increase in individual elements of the antioxidant defence of the organism [20,21].

Grabski’s study also confirmed the effect of sulphide water on antioxidant defence indicators in patients with rheumatoid arthritis, showing an increase in the activity of individual elements of the antioxidant system [22].

Research carried out by Misztela on the use of artificial sulphide and hydrogen sulphide baths in the treatment of rheumatoid arthritis (RA) patients showed an improvement in their clinical condition by reducing pain, shortening the duration of morning stiffness, and decreasing swelling and the amount of anti-inflammatory medication taken. Laboratory tests showed a significant reduction in ESR (erythrocyte sedimentation rate), CRP (C-reactive protein) and α₂-globulin levels, Waller–Rose reaction titer, as well as the increased haemoglobin value, whose low level is indicative of rheumatoid arthritis [23].

Sulphide waters have keratolytic and keratoplastic effects; therefore, they are used in the treatment of dermatological diseases, including psoriasis. Especially useful in the therapy is the antipruritic effect due to blocking the release of inflammatory mediators [24]. Sulphur has been found to exhibit antifungal and antibacterial effects by reacting with free radicals in the deeper layers of the epidermis [25]. Sulphur, remaining on the skin surface, reacts with urea, leading to the formation of ammonium sulphide, which also has antiseptic properties [26]. In addition, by binding tissue oxygen, it slows down metabolic processes and decreases the mitotic activity of cells [27].

The presence of radon in the therapeutic water seems to be no less important. Radon waters are specific waters containing small amounts of the unstable radioactive element of radon and its decay products. Such waters are used in medicine, provided that the radon content in the water exceeds 74 Bq/L (2 nCi/L) and they meet the operational and hygienic requirements. Radon is commonly found in trace amounts in spring and river waters, but for medicinal purposes, it is obtained from natural outflows and boreholes.

Radon is a chemical element formed in the radioactive decay of uranium and thorium. It occurs as a colourless and odourless noble gas that dissolves well in water, especially in poorly mineralised or acidified water. Radon exists in the form of many isotopes, the precursor of which is radon-222, which is formed directly from radium-226 through alpha decay. The emitted alpha particles have low penetrating power but high ionising power. The half-life is 3.8 days. Radon in high doses has a negative impact on health, and its harmful effects include the damage of enzymes and nucleic acids, which leads to the formation of neoplasms. Therefore, this should be especially taken into account while using radon as a medicinal material. The basis for the rationality of the therapeutic effect of radon waters is the hypothesis of so-called radiation hormesis. This theory was developed in the 1940s for the needs of pharmacology and toxicology. It states that small doses of ionising radiation activate life processes. This theory resembles Arndt-Szulc’s rule, used in physical therapy and developed in the 19th century, which claims that low doses of physical energy stimulate life processes [28].
The concentration of radon in natural conditions fluctuates continuously throughout the day and also seasonally due to precipitation. In the course of therapy, losses of radon are also observed for technical reasons, including the accumulation of water in tanks, transfer through pipes, heating, cooling, as well as intensive exploitation. A decrease in the radon content of 40–80% was observed. Such a high variability of radon concentration at the well sampling sites means that the calculation of any dose, whether total or organ dose, after taking into account the radon content in the source as well as the number of treatments taken, is impossible, inappropriate, and should not be used [29].

Radon penetrates the skin in small amounts, and the content increases with increased temperature and humidity. Absorption of radon occurs in 95% in the lungs; more than 90% of it is eliminated by exhalation in the lungs, and the remaining part is eliminated through the kidneys and skin. During a bath, absorption takes place mainly through inhalation, because radon and its derivatives accumulate in large amounts above the water surface. The lungs are particularly exposed to radon due to the deposition of decay products in the alveoli. On the other hand, the radioactive deposit settles quite permanently on the skin and stays there for several hours. The radioactive decomposition in the body varies greatly and largely depends on the amount of adipose tissue in different organs. Radioactive decomposition is mainly observed in adipose tissue, adrenal cortex, liver, and muscles [30].

The anti-inflammatory, desensitising, and analgesic effect of radon can be explained by the stimulation of the adrenal cortex and increased production of steroid hormones. Radon water baths have an effect on hormonal regulation in both women and men. The increase of the activity of the endocrine glands lasting for about 3 months has been observed as well as an increase in the concentration of lutenising hormone and growth hormone in the blood serum, and an increase in cortisol, testosterone, estradiol, and estriol. In menopausal women, the elevated level of estradiol and follicle maturation hormone relieve symptoms of menopause, and in men, sperm count and motility improve. In men suffering from arterial hypertension, a decrease in mean blood pressure values and an increase in the levels of ionised calcium, parathyroid hormone, and calcitonin were observed under the influence of radon baths [31].

Radon baths and therapeutic visits at the radon emanatorium in the natural medicine facility improve peripheral circulation and limb warming. They have an impact not only on reducing the swelling, joint, and tendon–muscle pains but also improving physical efficiency. Increased tolerance to physical effort directly after a radon treatment persists for up to one hour. Accelerated removal of harmful products of the metabolism was also observed, especially in diseases such as diabetes mellitus and gout. Under the influence of radon baths, arterial blood pressure is normalised, especially in people with mild hypertension, and a decrease in the level of total cholesterol and triglycerides is observed. This combination delays the occurrence of symptoms of atherosclerosis in peripheral arteries. Blood parameters also improve, with a decrease in erythrocyte sedimentation rate and an increase in haemoglobin and red blood cell count in the peripheral blood [32,33].

3. Conclusions

Radon–sulphide waters used in spa therapy influence the course of a number of systemic reactions. The mechanisms of these changes are still not fully understood. Physiological, biochemical, and cellular studies are repeatedly overtaken by clinical observations, hence the difficulty in determining various metabolic phenomena. Clinical observations show that in the case of spa medicine, obtaining positive effects of a therapy depends on the type and intensity of the applied stimuli, the reactivity of the body, individual sensitivity, the presence of other diseases, and genetically determined enzyme systems. The use of natural medicinal raw materials, e.g., therapeutic waters, is particularly difficult in therapeutic activities due to their low pharmacodynamic stability. Due to the metabolic activity of chemical compounds present in the therapeutic waters, the basis for any therapeutic action should rely not only on individually tailored and maintained therapies but also on further research in this area.
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