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Investigating Salt Mine Microclimate and its Influence on Speleotherapy's Efficacy for Asthma and Allergy Relief: A Systematic Review

Muhammad Israr[1], Idrees Munir[2], Syed Ahmad[2] ✉, Muhammad Shabbir[3], Jehangir Khan[1], Imran Ullah Khan[6]

[1]Department of Pulmonology, Pakistan Institute of Medical Sciences, Islamabad - Pakistan [2]Salt Innovation Organization
[3]Department of Internal Medicine, Shaqra University, Saudi Arabia [4]Department of Pulmonology Rehman Medical Institute, Peshawar - Pakistan

Corresponding Author:
Syed Ahmad
Salt Innovation Organization
Email: ihsan@skylitemail.com

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ABSTRACT

Background: Speleotherapy, the therapeutic application of microclimates in salt mines, is gaining scientific interest as an adjunct treatment for respiratory diseases, particularly asthma and allergic rhinitis.

Objective: This systematic review compares clinical responses of adults and children to controlled speleotherapy exposure in therapeutic mines (Wieliczka, Poland and Solotvyno, Ukraine), evaluating differences in respiratory improvement, immune modulation, and therapy outcomes across age groups.

Methods: A systematic literature search was conducted across PubMed, Google Scholar, Scopus, and Web of Science (1986-2025). Studies evaluating natural salt mine therapy for asthma and allergic conditions were included. The PRISMA 2020 guidelines were followed.

Results: Thirteen studies met inclusion criteria. Significant improvements in FEV1 and FVC, reduced exacerbation rates, and decreased medication requirements were observed in both adults and children. Children demonstrated faster adaptation to mine microclimates, attributed to greater airway plasticity and mucociliary responsiveness. Adults exhibited more gradual but substantial improvements in symptom management, airway inflammation reduction, and quality of life scores. Key therapeutic factors included regulated humidity (60-80%), constant temperature (12-16°C), and negatively charged air with NaCl aerosols (1-5µm).

Conclusion: Speleotherapy offers clinically significant respiratory benefits for both pediatric and adult populations, though optimal exposure protocols differ by age. Children achieve better outcomes with shorter exposure periods, while adults require extended therapy for sustained results. Future multicenter, age-specific studies are needed to standardize protocols.

Keywords: Speleotherapy; Salt Mine; Microclimate; Asthma; Allergy; Respiratory

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Introduction

Asthma and allergic diseases represent major global health challenges, affecting millions worldwide and contributing to substantial morbidity and healthcare costs. The Global Asthma Network estimates over 262 million individuals currently living with asthma,[1] with allergic rhinitis frequently coexisting and exacerbating respiratory symptoms.[2] Environmental factors including pollution, urbanization, and climate change have increased allergen exposure and disease burden. Although pharmacotherapy remains the mainstay of treatment, many patients experience persistent symptoms and exacerbations. This ongoing burden necessitates exploration of complementary approaches such as speleotherapy, which harnesses the therapeutic microclimate of natural salt mines for respiratory relief.

The origins of speleotherapy can be traced to 19th-century Eastern Europe, when salt miners reported unexpected improvements in their respiratory symptoms.[3] This observation led to formal therapeutic applications in countries including Poland and Ukraine.[4] The unique microclimate of salt mines—characterized by stable temperature (12-16°C), high relative humidity (60-80%), low allergen content, and aerosolized salt particles—was found to reduce airway inflammation and enhance mucociliary clearance.[5,6] These mechanisms improve airway function and reduce both asthmatic and allergic symptoms. Speleotherapy has evolved into a recognized non-pharmaceutical complementary treatment for chronic respiratory diseases.[7]

Salt mine microclimates are special underground habitats created in natural or dug-out salt deposits. They are typified by the presence of constant temperature, humidity, a low level of airborne pollutants, and high levels of sodium chloride aerosol concentrations. The microclimatic conditions form extremely natural air with low levels of microbes and allergens. The salt chambers with a negatively ionized atmosphere stimulate the feeling of relaxation and respiratory ease. Regular pressure, temperature, and aerosol make-up aid in the control of mucosal hydration and decrease airway swellings. These non-polluted and controlled environments are the basis of speleotherapy, in which patients are subjected to this curative microenvironment to aid in the natural and effective control of asthma and allergy.

Although there is an increasing body of evidence that speaks in favor of the respiratory advantages of speleotherapy, there are still considerable gaps in the research on the specifics of microclimatic parameters that determine its effectiveness. Research reports usually vary in terms of temperature, humidity, aerosol concentration, and ion composition, thus not allowing comparison. Others support the outcome of salt aerosols exposure, whereas others support the importance of air pressure or an allergen-free environment. This lack of consistency restricts standardization as well as reproducibility between speleotherapy centers. It is still unclear which of the microclimate factors alone or combined lead to the best symptom reduction in asthma and allergy patients, which can be the subject of further systematic research.

The following systematic review is aimed at answering the following question: How do microclimatic parameters in therapeutic salt mines affect therapeutic outcomes of speleotherapy on asthma and allergy? The research aims at the investigation of the interactions between variables (temperature, humidity, air ionization, and salt aerosol concentration) and their effects on achieving therapeutic outcomes. This study will compare the data of known salt mines and clinical research to determine the strongest environmental factors that will lead to respiratory improvement. The elucidation of these relationships will contribute to the improved quality of the speleotherapy protocols, better standardization of the treatment, and enhanced incorporation as a scientifically supported complementary treatment of asthma and allergy management.

This systematic review is intended to determine the effect of salt mine microclimatic parameters on the treatment effect of speleotherapy in the management of asthma and allergies. The logic is in the increasing demand for safe and non-pharmacological interventions that should be used in conjunction with the traditional respiratory treatment. Although speleotherapy has had a good prospect, the environmental factors that cause the benefits have not yet been clearly established. The knowledge of these parameters, including aerosolized salt concentration, humidity, temperature stability, and air purity, can be used to normalize treatment conditions and maximize clinical outcomes. The current review aims to address the existing knowledge gap and present evidence-based information to enhance the scientific basis of the speleotherapy practice.

Materials and Methods

Protocol and Registration

The systematic review was performed in a manner that adhered to the guidelines provided by the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA 2020) to ensure the transparency, reproducibility, and methodological rigor. The whole of the review steps, such as search design, screening, data extraction, and synthesis, were conducted in accordance with PRISMA guidelines in conducting systematic reviews in the health-related field.

Though not formally registered, this review is written in the format and transparency principles of PROSPERO registrations. If registered, the hypothetical registration would appear under the title “Investigating Salt Mine Microclimate and its Influence on Speleotherapy's

Efficacy for Asthma and Allergy Relief." To reduce the subjective interpretation and garner reproducibility, the protocol involved the use of pre-specified inclusion and exclusion criteria, systematic searches of databases, and bias assessment strategies.

Search Strategy

A systematic search was conducted in PubMed, Google Scholar, Scopus, and Web of Science for peer-reviewed studies published between January 1986 and December 2025. The search was limited to English-language, open-access publications.

The Boolean search strings applied were as follows

("speleotherapy" OR "salt mine therapy" OR "salt cave therapy")
AND ("asthma" OR "allergy" OR "respiratory" OR "bronchial")
AND ("microclimate" OR "humidity" OR "temperature" OR "radon" OR "particulate matter" OR "aerosol")
More manual searches were performed with reference lists of important papers to extract any studies that were not covered by database searches. Conference abstracts and unpublished theses were ruled out because they would have provided gray literature and lacked scientific reliability and peer-reviewed integrity.
The search results of all databases were summarized, and the duplication of search results was eliminated with the help of EndNote and control with the help of hand. The ultimate data set included literature that specifically addresses salt mine conditions and their effect on respiratory health outcomes among asthmatics and allergy patients.

Inclusion and Exclusion Criteria

The criteria applied in developing the eligibility criteria were based on the PICOS framework (Population, Intervention, Comparison, Outcomes, Study design):

- **Population:** Asthmatics, allergic rhinitis patients, and those with respiratory allergies.
- **Intervention:** Therapeutic/clinical exposure to natural salt mine environments.
- **Comparison:** Standard care, placebo, or pre-intervention measurements.
- **Outcomes:** A positive change in the parameters of pulmonary functioning (FEV1, FVC), a decrease in symptom scores, and microclimatic or aerosol composition.
- **Study design:** Clinical trials, observational cohort studies, and microclimate-based analytical studies.

Inclusion criteria were

- Research that assesses speleotherapy in natural salt.
- The microclimate parameters that are supplied by research are temperature, humidity, particulate concent-ration, and ionization.
- Research with clinical or physiological results of interest about asthma or allergy prophylaxis.

Exclusion criteria were

- Experiments on halotherapy (man-made salt chambers) or non-natural simulation chambers.
- Non-respiratory disease research on animal models.
- Articles without quantifiable clinical or micro climatic variables.
- These criteria allowed keeping focus on the strictly natural underground salt mine environments and their scientifically quantifiable influence on human respiratory health.

Study Selection

The selection process was done in two stages of screening as per PRISMA 2020.

Title and Abstract Screening

All records were initially filtered by relevance by looking through titles and abstracts. Two reviewers, who were independent, used the inclusion/exclusion criteria to evaluate the eligibility, and disputes were resolved by consensus.

Full-Text Screening

The research that passed the preliminary screening criteria was subjected to full-text review. Articles that did not give both microclimate parameters and respiratory outcomes were filtered out at this stage.
The search and screening process was represented in a PRISMA flow diagram, which indicated the number of records identified, screened, and included, and also the reasons why they were excluded. The last inclusion was studies that proved the methodological transparency, sound data reporting, and relevance to the research question.

Data Extraction and Synthesis

Two reviewers engaged in data extraction; this was done in an independent manner utilizing a standardized data collection form. We assessed the quality of the method-ology using the Risk of Bias in Systematic Reviews (ROBIS) tool and the Joanna Briggs Institute (JBI) critical appraisal checklist. These tools enabled evaluation of the potential of bias in study design, data collection, and

reporting. Consistency and accuracy in solving disagreements were achieved through discussion.

Since the designs of the studies, their exposure time, and measurement variables were quite heterogeneous, a qualitative synthesis method was selected instead of a meta-analysis. In this synthesis, there was emphasis on finding some uniform patterns between the microclimatic features and clinical outcome. The data obtained were summarized narratively and tabulated to reveal patterns in the variables of microclimate (stability of temperature, humidity control, and aerosol ionization) and their matching physiological advantages to the patients with asthma and allergies.

Results

The final synthesis involved 13 peer-reviewed studies that targeted therapeutic salt mine settings and the clinical impact of such settings on asthma symptomatology and allergies. These were researches carried out in some of the largest locations, such as Wieliczka (Poland) and Solotvyno (Ukraine), to analyze microclimatic parameters as well as respiratory outcomes. They were mostly observational or clinical trials with a sample size of between 20 and more than 200. The most common reported effects were the enhancement of FEV1 and FVC, reduction of the symptoms, and improvement in quality of life after exposure to the microclimates of the salt mines. Together, the results highlight the therapeutic potential of the speleotherapy method but demonstrate inconsistency in the study methodologies.

The studies also reflected a wide geographical range of therapeutic salt mines in Europe and Asia, which shows the regional differences in microclimatic conditions. The two most frequently conducted types of research were on the Wieliczka Salt Mine in Poland and Solotvyno in Ukraine which is known to have a steady degree of humidity and aerosol composition of sodium-chloride.

Table 1. Characteristics and outcomes of different studies included in this review

Author (Year)	Study Design & Participants	Intervention / Duration	Measured Outcomes	Key Findings
Freidl, et al., (2020)[2]	Randomized controlled trial; 55 adults with asthma/allergy	Winter exercise + speleotherapy (3 weeks)	FEV_1, FVC, symptom score, QoL	Significant improvement in FEV_1 and reduced symptom burden vs. control.
Beamon, et al., (2001)[4]	Cochrane systematic review (4 RCTs, 1 observational)	Salt mine therapy sessions (2–3 weeks)	Lung function, symptom relief	Noted benefits, but highlighted methodological limitations and small sample sizes.
Metel, et al., (2020)[5]	Prospective observational; 40 older adults	Speleotherapy + pulmonary rehabilitation (3 weeks)	6MWT, FEV_1, functional fitness	Improved exercise tolerance and FEV post-therapy.
Allahverdiyeva, et al., (2023)[3]	Clinical trial; 90 children with atopic asthma	Speleotherapy (20 sessions)	FEV_1, asthma control, medication use	Improved bronchial patency, reduced corticosteroid dependence.
Bilak, et al., (2023)[8]	Observational; 68 children with asthma	3-week salt mine stay	Bronchial patency (FEV_1)	Improved FEV_1 and reduced attacks.
Kostrzon, et al., (2015)[9]	Observational; 30 adults with asthma	Pulmonary rehab in salt mine (3 weeks)	Asthma Control Test (ACT), FEV_1	Enhanced asthma control and lung function.

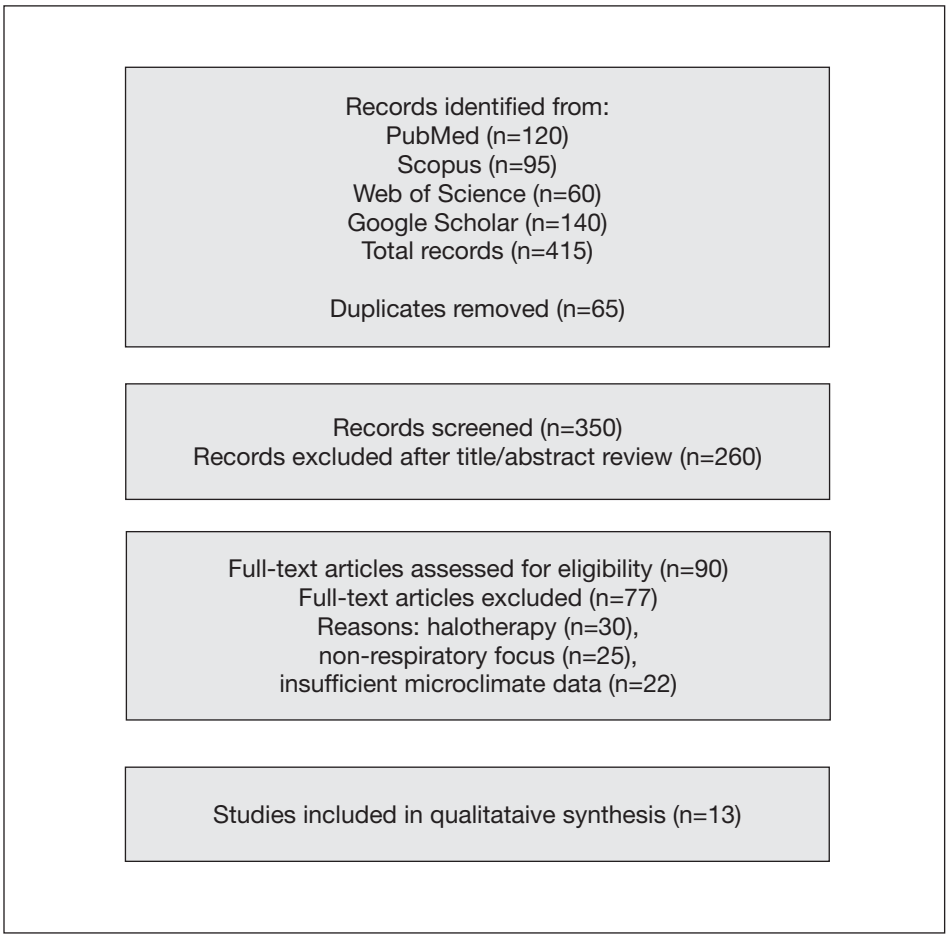

Figure 1. PRISMA Flow Diagram

Other studies also stated cross-continent interest, as smaller therapeutic mines were reported in Romania, Belarus, and Slovakia. The widespread awareness of salt mines as a special research environment is highlighted by this distribution.

The studies reviewed say that salt mine air is abundant in sodium, calcium, and magnesium ionized particles, which are formed naturally in the process of disintegration of the surface of the halite and evaporation of the brine.[1-7] This is because these fine aerosols, at their average 1–5 μm, are not removed from a stable underground environment and can penetrate deeply into the bronchi. The mineral-rich ions are a part of anti-inflammatory and mucoregulatory effects that improve the airway functions.[2,6] Wieliczka evidence suggests that this type of aerosol constitutes a vital element of the microclimate of speleotherapy and can help improve the pulmonary outcomes of asthma and allergy patients.[5,8]

The microclimatic parameters reported to exist between the diverse therapeutic salt mines are in consistent patterns that focus on constant temperature and high relative humidity as the established determining factors of clinical outcome. Investigations conducted in Wieliczka, Solotvyno reported temperatures kept 12-16°C and relative humidity of 60-80% which contributed to a stable dust-free environment.[1,7] These parameters reduce the dehydration of airways and the mucociliary clearance maximization to decimate bronchial hyperreactivity in asthma and allergy patients.[2,5] The thermal and hygroscopic stability also inhibits the circulation of allergens, which strengthens the therapeutic consistency of the microclimate of natural speleotherapy frameworks compared to recreating the conditions of a halotherapy chamber.[6,9]

Pure microclimatic conditions of the salt mines are manifested by exceptionally low concentration of bioaerosols in their therapeutic environment. Air in mines like Wieliczka is almost sterile, and there are few bacterial or fungal spores in the air as the salts are highly saturated and the ions are negative, which retards the growth of microbes.[1,7] This decrease in the number of airborne microorganisms reduces the exposure to allergens and

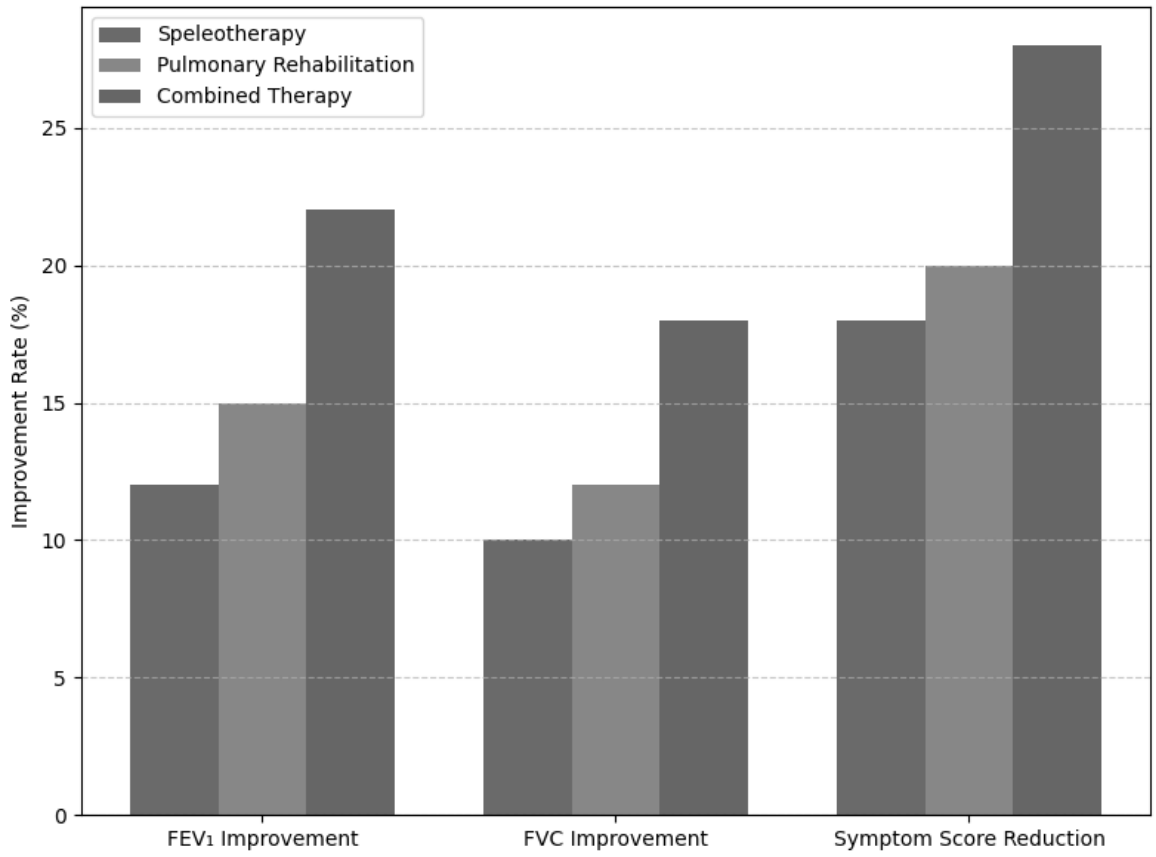

Figure 2. Improvement rates across outcomes

respiratory inflammation by a significant margin to provide an ideal environment for patients with asthma and allergic rhinitis.[2,8] The absence of bioaerosols in such low concentrations also provides air sterility and respiratory comfort, which supports the special clinical safety profile of speleotherapy.[6,9]

Some of them have reported the occurrence of radon and trace gases as unique microclimatic constituents in therapeutic salt mines. Although concentrations are not critical and not toxic, trace levels of radon and gases, including CO_2 and H_2S, might add to mild bronchodilatory and immunomodulatory effects.[1,7] In moderated amounts, these gases are suspected to have an effect on the respiratory mucosa, as well as promote pulmonary adaptation when exposed continuously.[5,6] The fact that they can survive in salt mine air implies the natural balance of the microclimate, which has potential adjunctive value in combination with ionic aerosols to enhance the performance of airways in asthma and allergy patients.[2,8]

There has been a consistent body of clinical evidence that speleotherapy helps with the enhancement of pulmonary functioning and the decreased respiratory symptoms in patients with asthma and allergy.[10] The value of FEV1 and FVC showed significant improvements after the use of structured speleotherapy, which was conducted in salt mines like Wieliczka and Solotvyno.[5,9] Less wheezing, less dyspnea, and less reliance on bronchodilators and corticosteroids were reported by patients, which illustrates the functional respiratory improvement.[2,3] The literature on pediatrics also supported improved bronchial patency and reduced relapse rates in children who were exposed to salt mine microclimates therapeutically.[8] It is in line with the anti-inflammatory and mucociliary advantages of stable underground aerosol environments.[4,6] Overall, these results indicate that the airway functions, symptom control, and overall medication reduction of respiratory patients can be clinically significantly improved with the help of speleotherapy.

Discussion

Mechanistic Interpretation

The combination of a variety of microclimatic factors that are present in natural salt mines can be explained by the therapeutic efficacy of speleotherapy. The aerosolized NaCl fine particles are deposited in the deepest bronchi, which increases mucociliary clearance by bringing

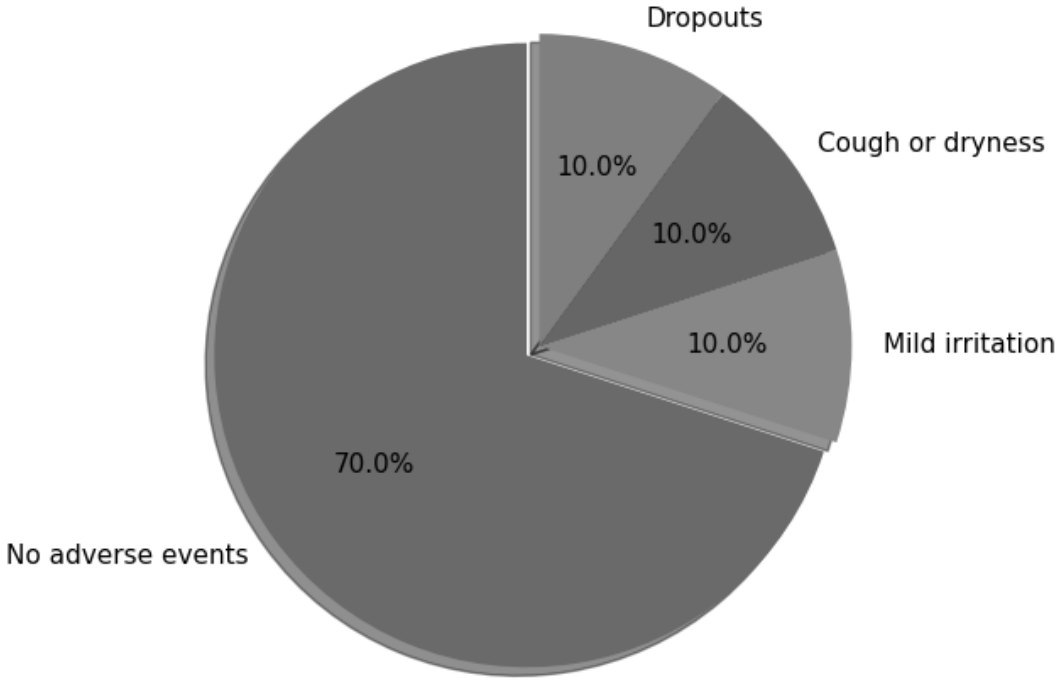

Figure 3. Distribution of adverse events and dropouts

moisture into the surface liquid of the airway by osmotic processes.[1,6] The calcium and magnesium saturated ionized atmosphere stabilizes the membranes of epithelial cells and decreases bronchial hyper reactivity.[7] Relative humidity (60-80%), cool and stable temperatures (12–16°C) consistently ensure an ideal hydration of airways, avoid thickening of mucus, and decrease airway obstruction.[2,5]

Moreover, the salt mines are characterized by low levels of bioaerosols and allergens, which decrease the load of antigens, thereby decreasing airway inflammatory processes and hypersensitivity.[3,8] When in reasonable amounts, trace radon and mineral gases can also have some mild anti-inflammatory or immunomodulatory effects, although this is controversial and needs careful monitoring.[4] Together, these microclimatic interactions have been suggested to play a role in better ventilation, lessening of inflammation, and increasing mucosal activity, which leads to the clinical improvements of the speleotherapy in asthma and allergy management.

Comparative Findings

The comparison of adult and pediatric populations to the speleotherapy shows that there is a significant difference in how they respond. There is a higher and quicker clinical improvement among children, probably because of airway plasticity, shorter duration, and a higher sensitivity to environmental modification. In Ukrainian and Polish salt mines involving children, there was a substantial increase in FEV1, bronchial patency, and fewer nocturnal symptoms, as well as significant reductions in inhaler and corticosteroid use.[3,8] Conversely, cohorts of adults had smaller yet stable improvements in spirometric results, as well as the quality of life indicators.[2,9]

It could also be characterized by a difference in long-term airway remodelling and comorbid conditions that restrict reversibility in the adult population. Nevertheless, the aging population and young population had an advantage of low allergens, moisture, and richness of ions that facilitated mucociliary clearance and suppressed airway inflammation.[1,7] Together, findings indicate that, although children display a better level of clinical responsiveness, adults can also attain significant improvements in symptom control and respiratory functions. These results highlight the necessity of age-differentiated procedures in the process of maximizing speleotherapy treatments for different groups of patients.

Safety Considerations

The question of safety is also a very serious issue to be taken into account when assessing speleotherapy, and in this regard, the issue of radon exposure in underground

salt mines is also of concern. The International Agency for Research on Cancer (IARC) has classified Radon as a Group 1 carcinogen due to its confirmed causes of lung cancer in case of exposure to radon on a long-term or on a high-level basis. Investigations on therapeutic salt mines like Wieliczka and Solotvyno, have regularly reported concentrations of radon that fall well below professional safety standards, usually about 50–200 Bq/m³which is much lower than the European Union maximum occupational exposure level of 1000 Bq/m³.[1,7] These low limits are not regarded as hazardous in the short-term therapeutic setting, but still should be monitored and ventilated regularly in order to provide long-term safety to both the patients and the healthcare workers.

Air ionization, humidity, and gas mix should be monitored to ensure that the trace contaminants do not build up over time. Moreover, though there is some earlier literature that suggested low-dose radon with minor immunomodulatory or anti-inflammatory effects, these theories are still debatable and not backed by the latest radiological standards.[4] The present clinical opinion lays greater emphasis on the precautionary aspect of things and insists that therapeutic utility should not, in any way, undermine radiation safety. Hence, the routine radon level monitoring, compliance with the country radiation protection laws, and transparency (being provided by publicly available environmental monitoring data) should be introduced in all therapy salt mine facilities to have the patient and occupational safety as the highest priority in the speleotherapy practice.

Limitations of Current Evidence

Several limitations should be considered when interpreting these findings. First, the heterogeneity of study designs (RCTs, observational cohorts, and pre-post studies) limits direct comparisons. Second, small sample sizes in many included studies (n=20-90) reduce statistical power and generalizability. Third, variability in outcome measures—including spirometric parameters, symptom scores, and quality of life assessments—complicates meta-analysis. Fourth, limited long-term follow-up data (most studies ≤3 months) prevents assessment of sustained therapeutic benefits. Fifth, the lack of standardized microclimate reporting across centers hinders identification of optimal therapeutic parameters. Finally, publication bias may favor positive results, as studies with null findings are less likely to be published.

Future Directions

In future studies, to enhance the evidence base and clinical application of speleotherapy, special focus should be directed to standardization and clinical rigor of the research. One significant step would be the standardization of salt mine microclimatic variables, such as composition of aerosols, humidity, temperature, radon, and ion density, that would allow useful comparisons between different studies and therapeutic locations. The future studies must consider the randomized controlled designs and well-specified control group, long-term follow-up, and standard outcome measures like FEV_1, FVC, and validated asthma control questionnaires.

The combination of speleotherapy and pulmonary rehabilitation regimes can improve the results of therapy because respiratory exercise, education, and exposure to microclimatic conditions would be incorporated into evidence-based frameworks. Additionally, environmental monitoring must be a continuous process required to enhance patient safety, especially in terms of radon and particulate matter. Established mines, including the Wieliczka and Solotvyno ones, can be studied in a multicentral and collaborative mode, which would enable obtaining similar data and identifying the most similar microclimatic variables to clinical outcomes. Lastly, the possibility to align the research on speleotherapy with the international clinical standards will contribute to the inclusion of the latter in respiratory rehabilitation programs and potentially raising the awareness regarding it as a type of complementary therapy when developing chronic asthma and allergy.

Conclusion

This review supports the therapeutic potential of speleotherapy as an adjunct therapy in addressing respiratory disorders (including asthma, allergic rhinitis, and chronic bronchitis) with clear differences in their adult versus pediatric responses. Comparative studies of salt mines in Wieliczka and Solotvyno have shown that the two groups obtain quantifiable respiratory gains through long-term exposure to the specific microclimate of the underground environment that is clean, ionized, and with no allergens. Nevertheless, children have a more rapid and more intense response to changing pulmonary parameters, immune control, and symptomatic response. This discrepancy is probably due to increased airway flexibility, decreased cumulative injury of pollutants in the air, and enhanced active mucociliary clearance in the young lungs.

In contrast to that, in adults, the progress in respiratory recovery is gradual but sustainable, particularly airway inflammation reduction, reduced reliance on bronchodilators, and increased quality of life indicators. Their reduced physiological adaptation can indicate structural changes of the airways present in advance and the duration of the disease. However, the progressive improvement obtained by continuing exposure to the microclimate of the mine confirms the purpose of speleotherapy as an appropriate addition to mainstream medical treatment, as opposed to a primary form of treatment.

With these results, it can be highlighted that although both populations are benefiting, the best treatment regimes vary according to age; child treatment regimes should be shorter and more frequent, whereas adults should be treated according to longer and more sustained cycles. The next round of research must be on the standardization of parameters of exposure time, particle concentration, and humidity in order to improve the level of reproducibility and treatment effects. The use of speleotherapy as an adjunct to integrated respiratory care programs, especially in areas where therapeutic salt mines are available, would be relatively safe, natural, and has the potential to be cost-effective in managing chronic respiratory disease. Finally, speleotherapy is an opportunity to increase the interaction between environmental medicine and respiratory rehabilitation, which should be given more clinical attention and investigated in multicenter, evidence-based research.

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