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Accidents in speleology: Analysis of major risks and preventive measures

Acidentes em espeleologia: Análise dos principais riscos e medidas de prevenção

Accidentes en espeleología: Análisis de los principales riesgos y medidas de prevención

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Abstract
Objective: To identify the most common accidents in speleology and their prevention measures, collect statistical data on rescues, and determine the most common risk factors among sports enthusiasts. Method: Systematic Literature Review using the PubMed and BVS databases. The PIO structure was used to outline the components of the research question, and the PRISMA method was employed for article selection. We selected articles published between 1999 and 2022. Results: The most common accidents are falls, collapses, and floods, with the incidence of rescues varying by country. Risk factors include a lack of training and knowledge in rescue and first aid, as well as the absence of the use of personal protective equipment (PPE). Conclusions: The most common accidents in speleology are falls, collapses, and floods, which are often severe but preventable. Continuous safety training and interdisciplinary research are essential to reduce risks and enhance safety in this sport.
Keywords: Caves; Accident prevention; Accidents; Athletic injuries.

Resumo
Objetivo: Identificar os acidentes mais comuns em espeleologia e suas prevenções, coletar dados estatísticos sobre resgates, e determinar os fatores de risco mais comuns entre os esportistas. Método: Revisão Sistemática da Literatura utilizando as bases de dados PubMed e BVS. Utilizou-se a estrutura PIO para delinear os componentes da questão de pesquisa e o método PRISMA para a seleção dos artigos. Selecionamos artigos publicados entre 1999 e 2022. Resultados: Os acidentes mais comuns são quedas, desmoronamentos e inundações e a frequência de resgates varia conforme o país. Os fatores de risco incluem a falta de formação e conhecimento em resgates e primeiros socorros, bem como a ausência de utilização de equipamentos de proteção individual (EPIs). Conclusões: Os acidentes mais comuns em espeleologia são quedas, desmoronamentos e inundações, frequentemente graves e preveníveis. A formação contínua em segurança e a pesquisa interdisciplinar são essenciais para reduzir riscos e promover maior segurança na prática desportiva.
Palavras-chave: Cavernas; Prevenção de acidentes; Acidentes; Traumatismo em atletas.

Resumen
Objetivo: Identificar los accidentes más comunes en espeleología y sus medidas de prevención, recopilar datos estadísticos sobre rescates y determinar los factores de riesgo más comunes entre los deportistas. Método: Revisión Sistemática de la Literatura utilizando las bases de datos PubMed y BVS. Se utilizó la estructura PIO para delinear los componentes de la pregunta de investigación y el método PRISMA para la selección de artículos. Seleccionamos artículos publicados entre 1999 y 2022. Resultados: Los accidentes más comunes son caídas, derrumbes e

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inundaciones, y la incidencia de rescates varía según el país. Los factores de riesgo incluyen la falta de formación y conocimiento en rescates y primeiros auxilios, así como la ausencia de uso de equipos de protección individual (EPI). Conclusiones: Los accidentes más comunes en espeleogía son caídas, derrumbes e inundaciones, que a menudo son graves pero prevenibles. La formación continua en seguridad y la investigación interdisciplinaria son esenciales para reducir riesgos y promover una mayor seguridade en esta práctica deportiva.
Palabras clave: Cuevas; Prevención de accidentes; Accidentes; Lesiones deportivas.

1. Introduction

Speleology, the practice of exploring natural underground caves, has been gaining increasing popularity worldwide, particularly in the United States, where a significant number of enthusiasts engage in this activity (Cuenca et al.,2000; Torralbo,2013a). It is estimated that approximately two million people visit caves annually, participating in a wide range of activities, from low-risk guided tours to rigorous expeditions led by members of the National Speleological Society (Stella-Watts et al., 2012; Cowart et al., 2014; Tornero-Aguilera et al., 2020). These expeditions can last for weeks or even months, requiring skills such as climbing, crawling, and rope work in challenging terrains, including muddy and slippery surfaces (Igleja, 2011; Stella-Watts et al., 2012).

Although safety is a priority within the speleological community, the inherent risks of the activity, such as rockfalls, extreme temperatures, and contaminated air, still pose significant threats (Igleja, 2011; Stella-Watts et al., 2012). Recent research has focused on developing rescue techniques and improving equipment for these environments, although data collection on specific accidents remains limited (Stella-Watts et al., 2012; Antoni et al., 2017; Tornero-Aguilera et al., 2020).

The growing interest in this physical and sports activity in natural environments positions speleology as a practice that combines adventure with intense physical and psychological challenges (Cuenca et al., 2000; Tornero-Aguilera et al., 2020). These environments demand adaptive cognitive skills similar to those observed in military contexts, where quick and precise decision-making is essential for personal safety (Igleja, 2011; Cowart et al., 2014; Tornero-Aguilera et al., 2020).

In Spain, speleology has a rich history, with significant advancements since the 19th century when Font i Sagué established the foundations of scientific speleology in the country (Cuenca et al., 2000; Antoni et al., 2017), currently, speleological activities in Spain range from simple visits to prolonged expeditions, which require high energy expenditure and involve complex environmental challenges (Alonso-Barajas, 2005; Stella-Watts et al., 2012; Antoni et al., 2017). Safety remains a primary concern for speleologists, considering the risks associated with unknown and often inaccessible underground environments (Alonso-Barajas, 2005; Igleja, 2011; Torralbo, 2013a; Cowart et al., 2014).

The Felix Ugarte Association, founded in Spain in 2000, aims to explore and study the mountains of Gipuzkoa, known for their extensive networks of natural caves. The association not only seeks to protect the subterranean environment but also promotes cave topography and documentation, organizing events and courses to raise awareness and improve safety among speleologists (Felix Ugarte Elkartea, n.d.).

In this context, speleological practice intersects with the field of Sports Nursing, emphasizing the importance of qualified professionals in performing interventions across various aspects of this activity (Ordem dos Enfermeiros, 2021). In Portugal, sports nursing has been established as a specialization, with nurses responsible for providing integrated care in multidisciplinary settings, promoting athlete well-being, and ensuring safety in sports practice (Ordem dos Enfermeiros, 2021). However, countries like Spain still lack formal specialization in sports nursing.

Sports nursing plays a crucial role in addressing the increasing interest in regular physical activity as a means of health promotion (Cuenca et al., 2000; Muñoz Moreno et al., 2020). With the rising popularity of high-level sports competitions (Cuenca et al., 2000; Torralbo, 2013a; Muñoz Moreno et al., 2020), there is a growing demand for skilled

healthcare professionals, such as nurses, who can ensure the health and well-being of practitioners throughout all stages of training and competition (Tornero-Aguilera et al., 2020; Muñoz Moreno et al., 2020).

Sports nursing not only prevents injuries but also promotes the physical and psychological health of practitioners, both before and after sports participation (Cowart et al., 2014; Muñoz Moreno et al., 2020). Understanding the physical, psychological, and social challenges faced by athletes is essential for developing effective interventions that optimize performance and minimize health risks associated with competitive demands.

Given the complexity of the field and the scarcity of research on the topic, the following research question was formulated: "What are the most common accidents in speleology, and how can they be prevented?" The study aims to: identify the most frequent accidents in speleology and the corresponding preventive measures, collect statistical data on rescue operations, and determine the most common risk factors among speleologists.

2. Methodology

The present study is quantitative in nature, as demonstrated in Figure 1 (which presents the number of selected articles) and Graph 1 (which shows the percentage of accidents). It also has a qualitative component, related to the selected articles (Pereira et al., 2018).

This study is a Systematic Literature Review (Gomes & Caminha, 2014), conducted using the scientific databases PubMed and BVS. The research was carried out between November 2021 and January 2022. The PIO framework was employed to outline the main components of the research question: "What are the most common accidents in speleology, and how can they be prevented?"

Patient/Problem: Cave sports practitioners.
Intervention: Prevention and rescue measures in speleology.
Outcome: Reduction of accidents and increased safety during speleological activities.

DeCS and MeSH descriptors in English and Spanish were utilized to optimize the search, combining them using the Boolean operator "AND." The search strategies (BE) used in the databases were:

PubMed:

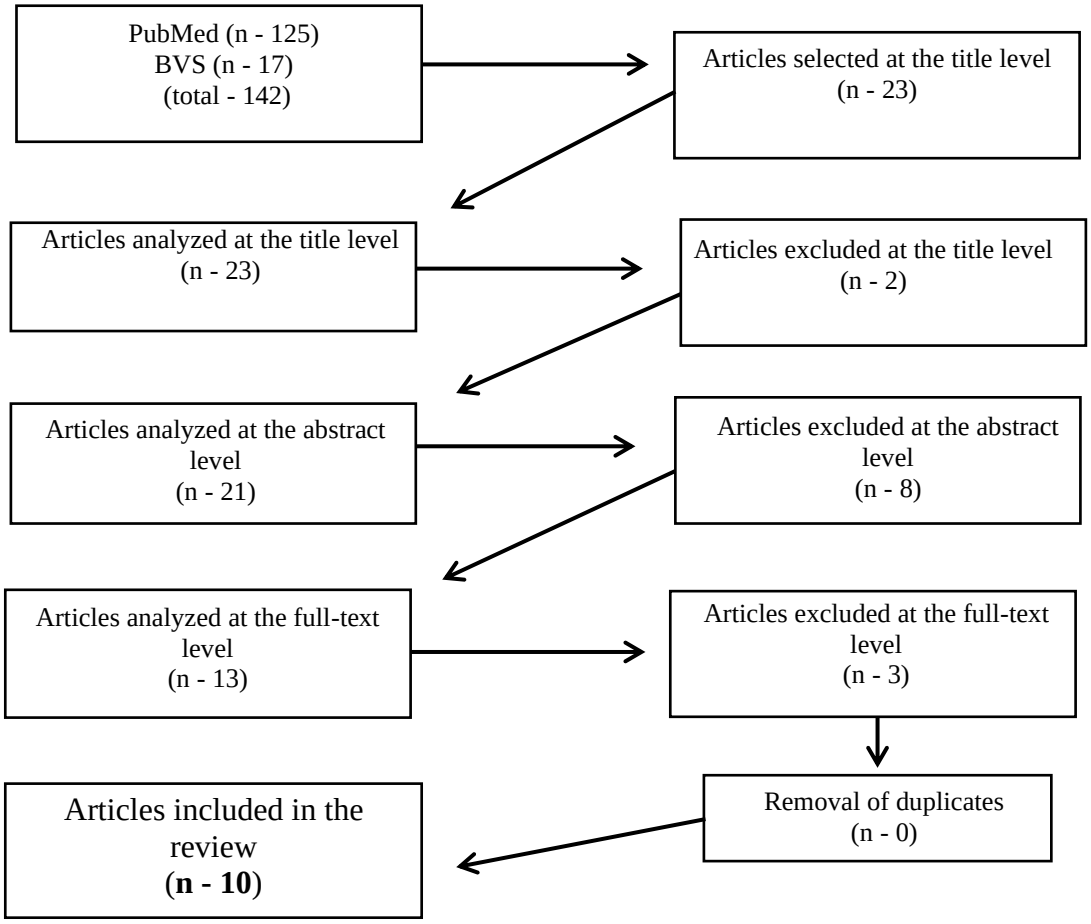
- BE1: (speleology) AND (accidents) AND (espeleología) AND (accidentes) - 1 article
- BE2: (caves) AND (prevention) AND (cuevas) AND (prevención) - 20 articles
- BE3: (caves) AND (accidents) AND (cuevas) AND (accidentes) - 9 articles
- BE4: (caves) AND (injury) AND (cuevas) AND (lesiones) - 67 articles
- BE5: (caving) AND (injury) - 19 articles
- BE6: (caving) AND (accidents) - 9 articles

BVS:

- BE1: (caving) AND (accidents) - 9 articles
- BE2: (caving) AND (accidents) - 8 articles

Inclusion criteria were strictly applied, covering studies published between 1999 and 2022 and written in English, Spanish, or Portuguese. Articles related to biology, geology, archaeology, construction safety, and mining were excluded. The article inclusion process was systematized in a PRISMA flowchart adapted by the authors, presented in Figure 1.

Figure 1 - PRISMA Flowchart for article selection.



Source: Authors (2024).

3. Results

After selecting the studies, the data were thoroughly analyzed by the authors to provide a clear and descriptive summary of the results. This process was essential to meet the study's objectives and research question. The selected studies were coded with the letters "P" and "B," corresponding to the first letter of the database from which they were retrieved. The selected studies are presented in Table 1. The results are analyzed below by topic.

Table 1 - Articles selected from the databases P - PubMed and B – BVS.

Title	Author(s)	Country / Year	Type of study
P1 - Injury among cavers: results of a preliminary national survey	Ashford et al., 1999	USA / 1999	Descriptive observational study
P2 - Rhabdomyolysis after Prolonged Suspension in a Cave	Wharton & Mortimer, 2011	USA / 2011	Case report
P3 - Infectious Diseases Associated with Caves	Igleja, 2011	Brazil / 2011	Clinical review
P4 - The Epidemiology of Caving Injuries in	Stella-Watts et al., 2012	USA / 2012	Descriptive study of

the United States			retrospective analysis
P5 - Changes in knowledge of bat rabies and human exposure among United States cavers	Mehal et al., 2014	USA / 2014	Cross-sectional study
P6 - Prevention and Treatment of Injuries from Cave Exploration in Hawai‘	Cowart et al., 2014	USA / 2014	Descriptive retrospective review
B1 - The Epidemiology of Caving Fatalities in the United States	Stella et al., 2015	USA / 2015	Retrospective analysis study
B2 - Energy expenditure in caving	Antoni et al., 2017	Italy / 2017	Descriptive observational study
P7 - Psychophysiological Stress Response of Novice Cavers in a Speleology Route	Tornero-Aguilera et al., 2020	Spain / 2020	Descriptive observational study
P8 - Suspension Trauma: A Clinical Review	Weber et al., 2020	USA / 2020	Clinical review

Source: Authors (2024).

Types of Studies

Observational and descriptive studies (P1, P2, B2, and P7), along with clinical and retrospective reviews (P3, P4, P6, B1, and P8), predominate among the analyzed articles. These approaches aim to understand the associated diseases, injuries, and physiological responses of speleologists. The focus on identifying and describing phenomena reflects the predominance of observational studies, while the reviews consolidate existing knowledge, providing a basis for future research and interventions.

Injuries and Safety in Speleology

Studies (P1, P4, P6, and B1) provide a detailed overview of injuries and fatalities associated with speleology, particularly in the United States. Study P1 estimates that the injury rate is approximately one per 1,990 hours of exploration, highlighting the need for robust preventive measures. This finding is corroborated by studies P4 and B1, which detail the epidemiology of cave-related injuries. Study P6, comparing data from the U.S. mainland and Hawaii, reveals a higher fatality rate in Hawaii, underscoring the importance of meticulous planning and education on specific local risks.

Diseases Associated with Speleology

Study P3 analyzes health risks, focusing on common infectious diseases in caves, such as leptospirosis and recurrent fever. The importance of preventive measures, including vaccinations and the use of appropriate protective equipment, is emphasized to safeguard speleologists from diseases transmitted by cave environments and animals.

Knowledge of Rabies and Exposure Among Speleologists

Study P5 assessed the knowledge of U.S. speleologists regarding bat-transmitted rabies, identifying an increase in awareness of the risks but also inconsistent adherence to pre-exposure prophylaxis recommendations. These findings reinforce the need for continuous education and preventive strategies to reduce the risk of infectious diseases.

Physiological and Psychophysiological Responses

Study P7 examines the psychophysiological response of novice speleologists, demonstrating an increase in perceived effort and alterations in autonomic heart rate control. These findings underscore the importance of adequate physical and mental preparation to cope with the physical and psychological stress associated with cave exploration.

Suspension Trauma

Studies P2 and P8 address suspension trauma, a severe condition in speleology incidents. Study P2 details a case of rhabdomyolysis following prolonged suspension, while study P8 discusses the pathophysiology and necessary interventions to prevent complications, such as the rapid removal of the individual and the adoption of a supine position as an initial measure to prevent cerebral hypoperfusion and other health damages.

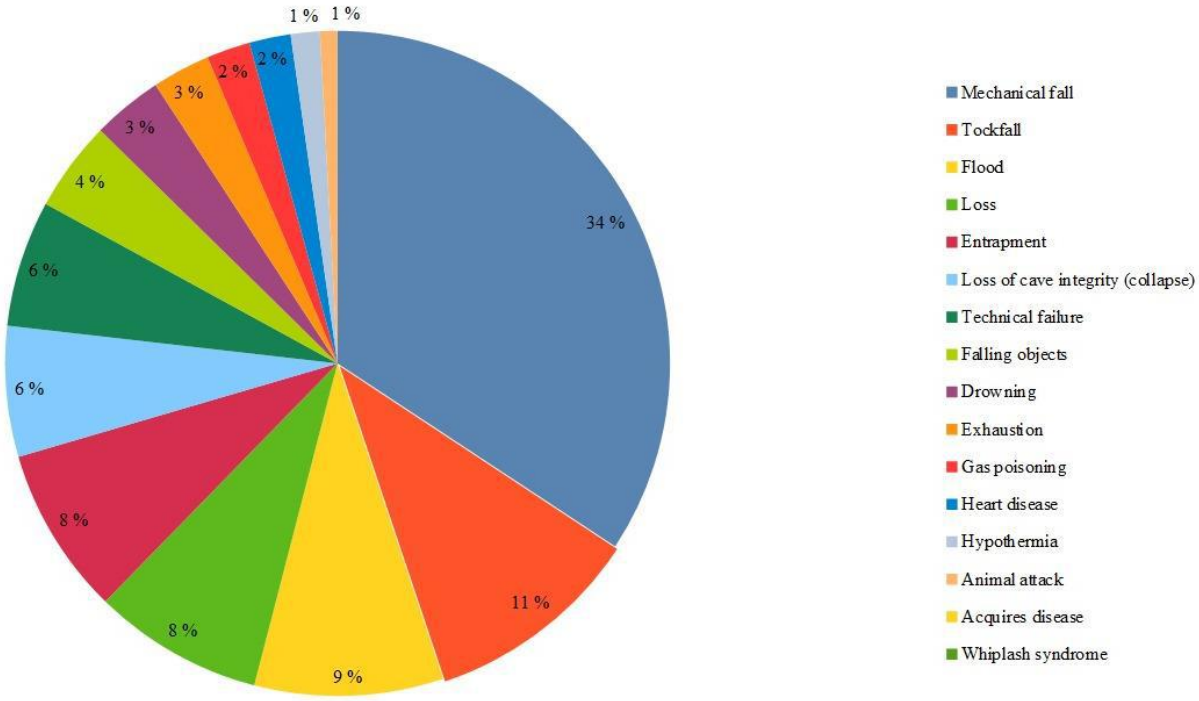
Geographical Contexts and Speleological Practices

The reviewed studies cover different geographical contexts. Articles such as P1, P4, and B1 focus on the United States, while study P6 expands the analysis by comparing data from Hawaii and the mainland. Study P3, conducted in Brazil, identifies specific infectious diseases in tropical caves, whereas B2, conducted in Italy, investigates the energy expenditure of European speleologists, and study P7, conducted in Spain, explores psychophysiological responses. This diversity highlights the universal challenges faced in speleology, reinforcing the need for preventive and management strategies adapted to the specific characteristics of each region.

Most Common Events and Accidents

Accidents in speleology are multifactorial, including falls and landslides, as reported in studies P4 and P6 (Dulanto, 2010; Janneteaue, 2019; Limagne, 2020). These events emphasize the importance of proper planning and safety measures. Graph 1 presents a graphical representation of the most common accidents in percentage terms.

Graph 1 - Representation of the most common accidents in percentage, own source.



Source: Authors (2024).

4. Discussion

Although speleology involves significant risks, it should not be considered an absolutely high-risk sport. Accident rates have considerably decreased over the years, reflecting a reduction in the likelihood of severe accidents according to studies P3 and B1 (Torralbo, 2013a; Lebeau, 2017; Janneteaue, 2019; Limagne, 2020). This improvement can be attributed to factors such as intentional training, better access management, and technological advances in safety and equipment (Lebeau, 2017). However, despite the increase in recent research, there is still a lack of consistent information on accidents and specific preventive measures for speleology, as evidenced by studies P4, B1, and B2 (Sánchez, 2017; Segurtasun Batzordea, 2018; Limagne, 2020).

The lack of standardization between federations and rescue teams, along with the higher frequency of self-rescue compared to available data, compromises the reliability of information, according to study P4 (Sánchez, 2017; Lebeau, 2017; Segurtasun Batzordea, 2018; Limagne, 2020). This inconsistency in the literature highlights the need for more detailed research to obtain precise information on accidents and their consequences, aiming at the development of more effective preventive measures (Lebeau, 2017; Janneteaue, 2019).

According to study B2, preventing hypothermia requires adopting measures such as wearing appropriate clothing and protective materials against the cold, avoiding prolonged contact with cold water, and consuming high-energy foods. Additionally, fatigue prevention requires speleologists to consume sufficient food and water, take regular breaks, and respect their limits (Alonso-Barajas, 2005; Segurtasun Batzordea, 2018). A well-planned diet should include balanced meals rich in carbohydrates (Torralbo, 2013b; Arteagoitia & Fernandez, 2019). Hydration is equally crucial, with regular intake of water or suitable beverages recommended during exploration (Torralbo, 2013b).

Accident and injury prevention requires a set of strategic actions. Careful expedition planning is essential, considering factors such as weather forecasts, topography, hydrological behavior, and the physical condition of participants, as discussed in articles P3, B1, and B2 (Alonso-Barajas, 2005; Waldron, 2007). Identifying risks in advance and informing someone about the expedition plan are fundamental practices, as highlighted by studies P3 and B2 (Segurtasun Batzordea, 2018). Additionally, specific training in geolocation, self-rescue, and first aid is indispensable, as recommended in studies P4, P6, P8, and B1 (Torralbo, 2013b; Segurtasun Batzordea, 2018). Proper use of personal protective equipment (PPE), such as harnesses, ropes, helmets, and securing accessories, should be ensured in all expeditions (Waldron, 2007; Torralbo, 2013b).

Global data on speleology accidents show that mechanical falls and slips are the primary causes of accidents, as identified in studies P4 and P6 (Dulanto, 2010; Lebeau, 2017; Janneteaue, 2019; Limagne, 2020). These causes reflect the challenging conditions of underground activities, where uneven terrain and difficult environments are common. The predominance of male victims, along with variations in the average age of accident victims (40 years in France and 28.7 years in the USA), suggests that factors such as experience and physical condition play a significant role in accident risk, as reported in studies P4 and B1 (Janneteaue, 2019).

The effectiveness of preventive measures, such as careful expedition planning, risk assessment, proper use of PPE, and specific training, is widely recognized as essential for ensuring speleologist safety (Alonso-Barajas, 2005; Torralbo, 2013b; Arteagoitia & Fernandez, 2019). The reduction in accident rates over time can be attributed to technological advances and improvements in safety practices. These improvements have been continuously observed when rigorous preventive strategies are implemented (Lebeau, 2017).

During cave exploration, speleologists are advised never to engage in the activity alone; groups of 3 to 4 people are preferable (Waldron, 2007; Torralbo, 2013b; Segurtasun Batzordea, 2018). The group should be homogeneous in terms of skill and include an experienced member familiar with the cave (Limagne, 2020). To avoid disorientation, speleologists should

occasionally look back and mark their path with footprints or visible markers (Cuenca et al., 2000; Segurtasun Batzordea, 2018). Additionally, it is essential to ensure ground stability, avoid jumps, and use proper rappelling equipment to reduce accident risks (Limagne, 2020).

Knowledge of cave climatology and hydrology is another essential aspect of safety. Understanding environmental conditions and using appropriate techniques for flooded cave situations are fundamental, as suggested by studies B1 and B2 (Segurtasun Batzordea, 2018; Arteagoitia & Fernandez, 2019). Additionally, keeping all vaccinations up to date, particularly against tetanus and rabies, and immediately disinfecting wounds are essential measures to prevent infections and complications from animal attacks, as indicated by research P3 (Mehal et al., 2014).

However, the lack of isolated effectiveness in the prevention subgroup can be attributed to the complexity of the factors involved, highlighting the need for an integrated and specific approach. This approach should consider all aspects of environmental conditions, speleologists' preparation, and the adequacy of preventive measures. As indicated by studies on the effectiveness of preventive measures, such as those highlighted in articles B2 and P8, implementing a well-coordinated set of practices is crucial to minimizing risks and ensuring safety.

Studies demonstrate that nurses specialized in sports nursing play a fundamental role in injury prevention and safety promotion, enhancing practitioners' physical, mental, and social capacities through quality care and health education training (Muñoz Moreno, 2017; Muñoz Moreno et al., 2020). However, Spain and other countries lack a formal specialization in sports nursing.

The literature highlights the importance of educational strategies to improve speleologists' knowledge and practice, as evidenced by studies P1, P3, and P5. The lack of standardization in data collection and the underreporting of self-rescue cases present challenges for a comprehensive evaluation of the effectiveness of these preventive measures, according to studies P4, B2, and P8 (Lebeau, 2017; Sánchez, 2017; Segurtasun Batzordea, 2018; Limagne, 2020).

These findings indicate that while training is a crucial component for speleologist safety, it is essential to continue developing and adapting educational programs that more effectively address specific areas of prevention and emergency response. Ongoing research and the implementation of best practices, as indicated in the literature, are fundamental to promoting the safety and well-being of speleologists in various conditions and contexts.

Future studies should explore not only the immediate causes of accidents but also contributing factors such as prior experience and first aid training. Additionally, standardizing data collection and reporting among countries and organizations may improve the quality of available information, contributing to the development of more effective safety guidelines tailored to different environmental conditions and cave types.

5. Final Considerations

The most common accidents in speleology include falls, collapses, and floods. These events are often severe but can largely be prevented through specific and general safety measures. It is important to highlight that 60.5% of speleology-related deaths occur immediately due to delays in initiating rescue actions, which frequently exceed two hours. This data underscores the logistical and technical challenges faced by rescue teams and reinforces the need to prioritize preventive measures over accident management.

The identified risk factors include the lack of familiarity among speleologists with basic health and safety concepts, which is considered a critical issue. Therefore, the implementation of specific and continuous training programs is essential to address the fundamentals and particularities of this activity. These programs should also include training in the correct use of

safety equipment and emergency response strategies, ensuring the internalization and practical application of the acquired knowledge.

Despite the potential relevance of nurses, with or without specialization in sports environments, this study revealed a lack of literature exploring their role in the context of speleology. This gap reflects the predominance of research focused on more popular sports and the limited investigation into accidents and safety in speleology. The scarcity of data reinforces the need for further interdisciplinary research integrating nurses and other healthcare professionals in the development of preventive measures and specialized training for this activity.

We emphasize the importance of expanding knowledge on prevention and risk factors in speleology. The integration of research, education, and continuous training is essential for advancing preventive practices and promoting a safer environment for participants in this challenging sport.

Regarding the limitations of this literature review, the previously mentioned scarcity of research on speleology and the lack of recent publications should be noted. It is necessary to expand the temporal scope to include studies from 1999 to 2022, as well as to address the predominance of observational and descriptive studies, which may limit the ability to establish robust causal relationships. Nonetheless, key criteria relevant to the research question were carefully selected.

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