REVIEW

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Sudden Cardiac Death during Mountain Sports Activities

Der Plötzliche Herztod bei der Bergsportausübung

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Summary

- **Sudden cardiac death (SCD)** is an unanticipated and dramatic event resulting from cardiac causes. First reports on SCDs during mountain sports activities date back to the 1970s and 1980s of the last century. Relatively large datasets have been collected in Austria from 1985 onwards initiating systematic recordings and analyses of risk factors and triggers of SCDs during mountain sports activities.
- **The results presented** in this publication are derived from a literature search on reported SCDs that occurred during selected mountaineering activities with particular regard to study findings based on data collected in Austria.
- **We found** a relatively low SCD risk during mountaineering activities, amounting to about 1 SCD per 1 million activity days when hiking, trekking or ski touring, which is even lower during downhill skiing but higher in competitive cross-country skiing. The risk is much higher in men than in women and increases sharply above the age of 34.
- **Main risk factors** include prior myocardial infarction, coronary artery disease, arterial hypertension, hypercholesterolaemia and diabetes mellitus type 2, but regular and sport-specific activities turned out to be important protective factors. Unaccustomed physical exertion, in particular on the first days in the mountains (altitude), prolonged activities without rest and insufficient energy and fluid intake represent important SCD triggers. Besides considering these potential triggers during mountaineering activities, sports medical examination, appropriate pharmacological therapy of risk factors and physical preparation represent preventive key elements.

KEY WORDS:
Exercise, Mountains, Cardiovascular, Risk, Triggers, Prevention

Zusammenfassung

- **Der plötzliche Herztod (PHT)** ist ein unerwartetes aber dramatisches Ereignis. Die PHT-Inzidenz in der Gesamtbevölkerung variiert zwischen 50 und 100 pro 100.000. Sie ist deutlich höher für Männer als für Frauen und steigt mit zunehmendem Alter, bei Personen mit Vorerkrankungen und bei ungewohnter körperlicher Belastung markant an. Erste PHT-Berichte bei Bergsportaktivitäten stammen aus den 70er und 80er Jahren des vorigen Jahrhunderts und ab 1985 starteten in Österreich systematische Erhebung über Häufigkeit, Risikopersonen, Risikofaktoren und Trigger für den PHT.
- **Die im Folgenden präsentierten Ergebnisse** basieren auf einer Literaturerhebung zu PHT-Daten beim alpinen und nordischen Skilauf, auf Skitouren, beim Bergwandern und Trekking unter besonderer Berücksichtigung der langjährigen Erhebungen und Analysen in Österreich.
- **Es zeigte sich,** dass Bergsport mit einem relativ niedrigen PHT-Risiko verbunden ist, in einer Größenordnung von etwa 1 PHT pro 1 Million Aktivitätstage beim Bergwandern, Trekking und auf Skitouren. Dieses Risiko ist beim alpinen Skilauf sogar noch niedriger aber beim Skilanglaufen (besonders bei Wettkämpfen) allerdings höher.
- **Das Risiko** ist für Männer weitaus höher als für Frauen und steigt mit zunehmendem Alter steil an. Hauptrisikofaktoren sind ein bereits vorangegangener Myokardinfarkt, eine bestehende koronare Herzkrankheit, Bluthochdruck, ein erhöhter Cholesterinspiegel und Diabetes Typ 2. Regelmäßige und sportartspezifische Sportausübung sind die wichtigsten Schutzfaktoren. Ungewohnte körperliche Belastung (bei niedriger Fitness), besonders am ersten Tag der Bergsportaktivität sowie lange Belastungen ohne Pausen mit Energie- und Flüssigkeitszufuhr sind als Trigger zu nennen. Neben der Berücksichtigung dieser Trigger bei der Bergsportausübung stellen die vorangehende sportmedizinische Untersuchung, eine wirkungsvolle pharmakologische Therapie bestehender Risikofaktoren und besonders auch die rechtzeitige körperliche Vorbereitung wichtige Präventivmaßnahmen dar.

SCHLÜSSELWÖRTER:
Sport, Berge, Herzkreislauf, Risiko, Trigger, Vorbeugung

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Introduction

Sudden cardiac death (SCD) is an unanticipated and dramatic event resulting from cardiac causes with infinitely great suffering for the immediate family and friends. The first scientific reports on SCD date back to the 1880ies (25). About 100 years later the number of scientific publications on this topic started to increase exponentially. Soon after the second world war, an increasing participation in mountain sports activities was observed. At the turn of the second millennium about 40 million downhill skiers and mountain hikers/climbers visited the Alps annually (14). This number amounted to 10 million for the mountainous regions of Austria, to about 35 million for the Western United States and to more

than 100 million worldwide (8). With regard to skiing activities, more than 2,000 downhill ski areas and a total number of about 400 million skier days each year have been estimated (40). Nowadays, tourists can easily access mountainous and high-altitude regions in all of the continents. Thus, an increasing participation of older individuals, also with pre-existing chronic diseases, it not surprising. As mountaineering and skiing are physically demanding activities, in particular when performed at higher altitudes, a non-negligible prevalence of cardiovascular events may be expected.

Whereas traumatic deaths related to these activities were well known from the beginning, the risk of non-traumatic deaths, i.e. SCD, was not recognized until later on. First reports on SCDs in mountain sports have appeared in 1978 (cross-country skiing) (42), in 1988 (downhill skiing) (36) and in 1989 (trekking) (38). Relatively large SCD datasets have been collected and analysed in Austria from 1985 to 1991 and published in 1993 (13).

From those and the many following studies we learned that the incidence of SCD in the general population varies between 50 and 100 per 100,000, being higher in men than women and increasing steeply with age (15). Coronary artery disease accounts for more than 80% of SCDs in those aged over 35 years (15). In contrast, the SCD incidence in athletes younger than 35 years is much lower, being 1 to 2 per 100,000 with hypertrophic cardiomyopathy as the most common underlying cause (23). Whereas habitual exercise may diminish the SCD risk, vigorous exercise was demonstrated as an important trigger of SCD in non-athletes and athletes as well (1, 39). As the vast majority of participants in mountain sports activities are recreational sportsmen/women of nearly all ages, a transient risk increase compared to that of the normal population can be expected. Beside mortality data, this review will provide a differentiated view on the SCD risk of various mountain sports activities and its potential modification by environmental conditions.

Methods and Definitions

A literature search was performed by screening databases (cut-off date February 2020; Pubmed/Medline, Web of Science, Science direct, and Scopus) using the following keywords and various combinations: sudden (cardiac) death, skiing, mountaineering, hiking, trekking, altitude. Titles and abstracts were assessed in order to cover all existing relevant data on sudden death events related to downhill and cross-country skiing, ski touring, mountain hiking and trekking. Pre-screening revealed a lack of appropriate data concerning mountain sports activities like rock and ice climbing, mountain biking and high-altitude expeditions and have therefore not been considered. Special attention was paid on data collected in the Austrian alps representing a unique data base covering complete and standardized long-term recordings (nearly 4 decades) on fatal events during mountain sports activities (8, 13, 14, 28, 29). All available data from the literature enabling SCD risk estimation have been included for comparison with data from Austria.

Definitions: Sudden cardiac death was defined as unexpected, non-traumatic death in individuals with or without pre-existing diseases who died within 1 hour of the onset of symptoms (14). Levels of altitude were categorized as low altitude (up to 1500 m), moderate altitude (1500-2500 m), high-altitude (2500-3500 m), very high altitude (3500-5500 m) and extreme altitude (>5500 m) (27).

Mountain sports activities: In downhill or alpine skiing lifts and cable cars are repeatedly used for ascending followed by sliding down on snow-covered prepared (or unprepared) slopes. Skis are equipped with safety (release) bindings where the sole of the ski boot is fixed. In contrast, ski tourers use climbing skins mounted on the running surface of the skis with bindings that permit free moving heels for the ascent. Skins are removed at the top and bindings can be fixed for downhill skiing. Cross-country skiing (or Nordic skiing) is performed on groomed trails with the use of lightweight skis, boots and bindings. Bindings permit free moving heels and cannot be fixed. Mountain hiking is defined as walking in a mountainous environment predominantly on marked trails and paths usually with the goal to reach a hut or a summit followed by descent on the same or another day. Trekking means walking long distances on multiple days often in high-altitude regions like those in Nepal or the Andes.

Results and Discussion

Frequency, Causes and Risk Factors of SCD during Mountain Sports Activities

Downhill Skiing

Based on a 32-year study performed in Australia, Sherry and Clout calculated 0.45 cardiac-related deaths per one million skier-days (about 1 SCD/2,200,000 skier-days) (36). Early autopsy results (n=135, 1978-1987 and n=78, 1987-1990) from the Austrian alps revealed that almost 25% were non-traumatic (sudden) deaths, myocardial infarction being the dominant cause, triggered by the elevated cardiovascular load at higher altitudes (3, 4). From 1985 through 1991 we recorded 416 SCDs in the Austrian Alps, representing approximately 30% of all deaths that occurred during mountain sports activities (13). About 90% of victims were males and the SCD risk increased sharply with age above about 35 years. We calculated 1 SCD per 1,630,000 skiing hours (1 SCD per about 400,000 skiing days) for males aged above 34 years (Table 1). Subsequently, data on risk factor profiles were collected from spouses or close relatives of skiers who suffered SCD and age matched controls as well (11). From this case-control study it was derived that skiers who suffered SCD, when compared to controls, had much more frequently prior myocardial infarction (MI) (41% vs. 1.5%), hypertension (50% vs. 17%), known coronary artery disease (CAD) without previous MI (9% vs. 3%),and performed less vigorous exercise (4% vs. 15%). Vigorous activities were defined as needing 6 or more metabolic equivalents (METs; 1 MET = 3.5 ml/kg/min oxygen uptake). Adjusted odds ratios for risk factors explaining the SCD outcome, based on logistic regression analysis, are shown in figure 1. Another study from the Austrian alps, including 207 SCDs from 2005 to 2010, revealed an incidence of about 0.4 cardiac deaths per 1 million skier days or about 1 SCD/2,500,000 skiing hours in the overall skier population (34). A recent study from the French alps reported characteristics of 136 cardiac arrests on ski slopes (median age: 56 years, IQR: 40-65). 89% were males and 41% were in shockable initial rhythm, 56% were asystole and 41% ventricular fibrillation/tachycardia) highlighting the importance of early medical interventions by professional rescue teams (41).

Cross-Country Skiing

Vuori and colleagues were the first to report on the SCD risk during cross-country skiing (42). These authors recorded 8 SCDs in a total of 1,030,000 cross-country hikes (1 SCD/128,750 hikes/skiing days or about 1 SCD/770,000 skiing hours). They calculated the risk to be about 4-5 times higher than that of the age-matched general population. SCDs occurred more often in men than women and affected individuals suffered mostly from CAD. High-speed skiing was a more important trigger than ›

Table 1

Comparison of the SCD risk between the considered mountain sports activities (rough estimation) (9, 10, 13, 34, 36, 37). *=Mainly based on data from competitions; SCD=Sudden Cardiac Death.

ACTIVITY	SCD RISK (OVERALL POPULATION AT RISK) PER NUMBER OF EXPOSURE DAYS	SCD RISK (MALES >34 YEARS) PER NUMBER OF EXPOSURE DAYS
Downhill skiing	1 SCD/2,200,000 - 2,500,000	1 SCD/400,000
Cross country skiing	1 SCD/40,000 - 130,000*	
Ski touring	1 SCD/1,120,000	
Mountain hiking	1 SCD/980,000	1 SCD/780,000
Trekking	1 SCD/1,000,000	

distance. Hoffmann and Minder estimated 1 death per 120,000 skiing hours among participants of the Engadine Ski Marathon (19). Farahmand and colleagues reported 13 death in 698,102 starters of the Vasaloppet ski races from 1970 through 2005 (17). Overall, 13 deaths (all males) occurred and 12 were due to cardiovascular diseases; 11 participated in the longest distance (90 km). If assuming an average exposure time of 8 hours, 1 SCD occurred per 465,401 skiing hours. Whereas myocardial infarction due to CAD may be the primary cause for SCD in the more recreational (and older) cross-country skiers (42), myocarditis, hypertrophic cardiomyopathy or myocardial infarction were reported causes for the Vasaloppet participants (17).

Ski Touring

There are only very few data available on the SCD risk during ski touring. Data from Austria show low numbers of SCD (<1.0/100,000) until the age of 59 years but then it increased steeply to 10.4 per 100,000 (male) ski tourers older than 59 years (9). The calculated overall SCD risk for Austrian ski tourers (non-members of Alpine Clubs, 54±13 years, 86% males) was about 1 SCD/1,120,000 ski tours (10). In contrast to the SCD risk presented for male downhill skiers above 34 years, this one is based on the overall Austrian population (of non-members of Alpine Clubs). This means that the population at risk includes all age groups of both sexes who were not members of Alpine Clubs. Generally, members of Alpine Clubs were less likely to suffer from SCD (20% lower SCD risk), possibly due to more regularly performing mountain sports activities (10).

Mountain Hiking

From the same survey (Austrian alps) mentioned above (13), we calculated 1 SCD per 780,000 hiking hours (1 SCD per about 200,000 hiking days) for males (about 90% of SCD victims) aged above 34 years. The subsequent case-control study revealed that hikers who suffered SCD, compared to controls, had much more often a prior MI (17% vs. 0.9%), known CAD without prior MI (17% vs. 4%), diabetes (6% vs. 1%), hypercholesterolemia (54% vs. 20%) (Figure 1). Again, those performing more regular mountain sports activities were less affected (31% vs. 58%). Adjusted odds ratios for risk factors explaining the SCD outcome, based on logistic regression analysis, are shown in figure 1. A study conducted in the Italian alps reported the occurrence of 1 SCD per 980,000 person days based on the overall study population (31), in contrast to only men over 34 years in the Austrian study (13) (Table 1). Again, men above 40 were primarily affected by SCD, in particular those not engaged in regular physical activity (31).

Trekking

One of the first reports on the death risk during trekking was published by Drs Shlim and colleagues in 1989 which has been updated in 1992 (37, 38). Authors found stable death rates from 1989 to 1992 amounting to 14/100,000 trekkers. Ten percent were (very likely) due to MI, indicating 1.4 SCDs in 100,000 trekkers (37). Assuming an average trekking duration of 14 days, about 1 SCD would occur per 1,000,000 trekking days. This number is very close to that reported from hikers in the Alps (31). Although there are several other reports dealing with mortality during trekking, no clear picture can be derived with regard to the SCD risk from the data provided (26, 43).

Potential Triggers for SCD during Mountain Sports Activities

Almost 50% of all SCDs recorded in the Austrian alps occurred on the first day of hiking or skiing (11, 12). They were most frequently observed in the late morning hours, and accumulated with increasing time from the last food and fluid intake. These facts suggest that physiological stress factors like unaccustomed physical activity, mental exposure, dehydration and depletion of carbohydrate stores result in elevated sympatho-adrenergic activity triggering unfavourable cardiovascular responses, e.g. tachycardia and elevated systemic blood pressure (1, 14, 20). The hemodynamic stress and catecholamine surge may increase myocardial oxygen demand, acute ischemia, disruption of vulnerable atherosclerotic plaques, platelet activation resulting in increased thrombogenicity, and thus provoke MI. Moreover, activation of the sympathetic nervous system might also raise the susceptibility to ventricular fibrillation (1). Also, extreme ambient temperatures and high altitude may constitute SCD triggers (5, 22). With regard to altitude, pulmonary hypertension when acutely exposed to high altitude (hypoxia) may contribute to left ventricular dysfunction in individuals suffering from heart disease (2). On the other hand, sleeping at somewhat higher altitude before exercising on the first day in the mountains may represent some SCD protection, likely due to pre-conditioning or short-term acclimatization (22).

Preventive Measures

The following recommendation will focus on the primary risk group performing recreational mountain sports activities, i.e. males aged 35 years and older. Regarding young people, in particular athletes, we refer to a comprehensive overview of the most updated recommendations for this population with cardiomyopathies and myo-pericarditis involved in competitive and recreational activities (30).

The most important measures to prevent SCD during mountain sports activities include sports medical examination, appropriate physical preparation, pharmacological therapy of cardiovascular risk factors, and the promotion of awareness of risk conditions and triggers during mountaineering activities.

Sports Medical Examination and Exercise Testing

Sports medical examination includes the assessment of general health and fitness status, screening for cardiovascular risk factors and coronary artery disease, and appropriate counselling how to change lifestyle and to prepare for safety mountaineering/skiing activities.

For males aged 35 or above, in particular those not accustomed to physical activity or experiencing symptoms like chest pain, irregular pulse, shortness of breath, dizziness or light-headedness, it is strongly recommended to undergo such sports medical examination including electrocardiogram (ECG) and, if indicated, exercise testing. As mentioned above, mountaineering and skiing activities often represent moderate- to high-intensity exercise and are increasingly performed by middle-age and older persons. Therefore, ECG-monitored incremental exercise test should be included whenever possible, for the detection of cardiovascular diseases, appropriate exercise prescription and the control of training progress as well. The important role of the systematic useof maximal exercise testing in detecting cardiovascular diseases has recently been demonstrated (16).

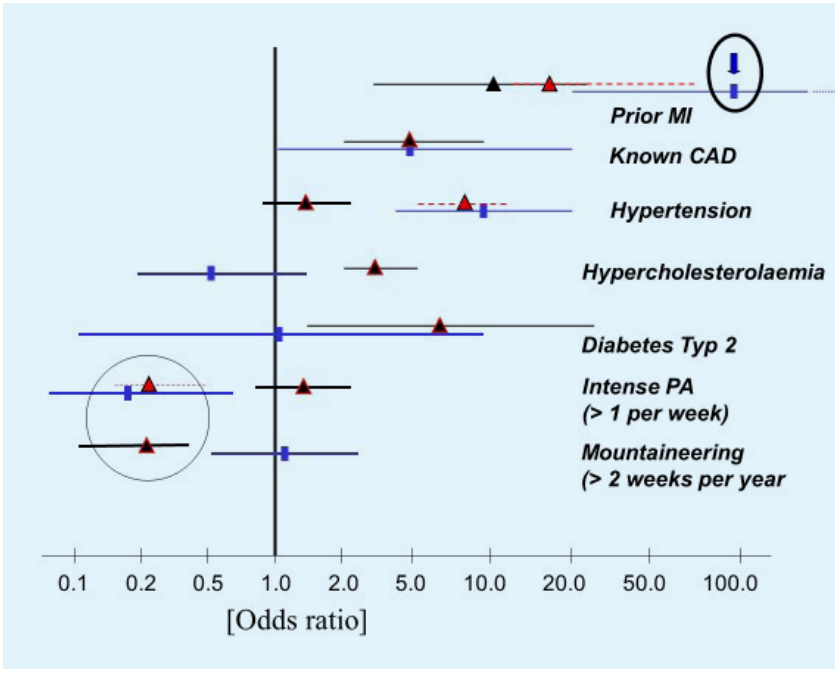

Figure 1

Adjusted odds ratios (95% confidence intervals) concerning the prevalence of risk factors among mountain hikers (black triangles), cross-country skiers (red triangles)* and downhill skiers (blue rectangles) who suffered SCD when compared to controls. Circles indicate the dramatic impact of prior myocardial infarction (MI) and the large beneficial effects of regular sport specific exercise. *=calculated from our unpublished data pool; SCD=Sudden Cardiac Death.

Exercise Training

Whereas the physical preparation of mountain hikers, trekkers, ski tourers, and cross-country skiers will primarily focus on continuous moderate aerobic exercise, downhill skiers should also include strength and intense interval training. General guidelines for exercise prescription are available from the American College of Sports Medicine (18, 32). It is important to recognised that mountaineering activities require a relatively high level of fitness to perform those activities safely and joyful (7). This fact underlines the importance to start soon enough with physical preparation before going in the mountains, i.e. at least 4 to 8 weeks, to achieve appropriate fitness.

Pharmacological Therapy

Appropriate therapy of cardiovascular risk factors like arterial hypertension, hypercholesterolaemia, diabetes and arrhythmias constitute important preventive measures. The therapeutic strategy may even be complemented by the use of targeted medication, e.g. acetylsalicylic acid and beta blockers, during the hazard period of a triggering activity (21, 35).

Awareness of Risk Conditions and Triggers in the Mountains

Finally, the consideration of certain behavioural aspects based on established risk conditions and potential triggers will help to prevent some SCDs during mountaineering activities. Preventive measures include rest on the first one or two days in the mountains and a gradual increase in activity on the following days, but also considering repeated rests with energy and fluid intake, i.e. every 30 to 60 minutes, during mountaineering activities. Moreover, spending the first night close to altitudes where those activities are performed may potentially support prophylactic efforts.

Besides the potential risks of mountain sports activities an overwhelming body of evidence shows that the potential benefits far outweigh the potential risk, especially if preventive measures as outlined above are considered (33).

Practical Considerations when Planning to Start Mountain Sport Activities

- sports-medical examination plus maximal exercise testing
- pharmacological therapy of cardiovascular risk factors (if necessary)
- supervised exercise training (4 to 12 weeks – to achieve appropriate fitness)
- eventually control examination (and exercise testing)
- progressively increasing mountaineering/skiing activities (sufficient recovery between activities)
- slow ascents to higher altitudes (rest or descent when experiencing complaints)
- repeated rests with energy and fluid intake during activity in the mountains
- use of mountain guides or ski teachers may be helpful

Limitations

The most important limitation may arise from the fact that a major part of available data stems from Austrian recordings and analyses. Unfortunately, data enabling SCD risk calculation are scarce in the international literature, primarily due to lacking information on the population at risk. Another limitation may be seen in the exclusion of rock- and ice climbing as well as high-altitude expeditions. This is primarily related to the fact that proper diagnosis after a fatal fall is challenging as autopsy is rarely performed. ›

Conclusion

The overall SCD risk during mountaineering activities is relatively low, amounting to about 1 SCD per 1 million activity days when hiking, trekking or ski touring, and is even lower during downhill skiing but higher in cross country skiing, especially when participating in competitions. Importantly, this risk is much higher in men compared to women and steeply increasing above the age of 34 years. Traditional risk factors include prior myocardial infarction, coronary artery disease, arterial hypertension, hypercholesterolaemia and diabetes mellitus type 2, however, regular and sport specific activities represent important protective factors. Unaccustomed physical exertion, in particular on the first days in the mountains (altitude), prolonged activities without rest and insufficient energy and fluid intake, may trigger SCD. Preventive key elements include sports medical examination and maximal exercise testing, appropriate pharmacological therapy and physical preparation, and the consideration of potential triggers during activities in the mountains.

Conflict of Interest

The authors have no conflict of interest.

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