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Physiology, Asthma and Injuries in High-Performance Adolescent and Young Adult Cross-Country Skiers

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Abstract

Cross-country skiing is a winter sport that consists of traveling generally long distances on uneven terrain with slopes that may be steep, but not continuous. A narrative review of the physiology, asthma, and injuries in high-performance adolescent and young adult cross-country skiers is carried out. From the point of view of physiology, this sport has helped to acquire new knowledge about the limits of human performance and regulatory capacity. The main physiological effects on the respiratory, cardiovascular, musculoskeletal, and energy systems are described. Being a high-performance cross-country skier is an independent risk factor associated with developing asthma, with the prevalence being 2 to 2.5 times higher and the age of onset later compared to non-skiers. It is usually well-controlled and requires regular maintenance treatment. This disorder is not an obstacle to practicing this sport. While it is generally a low-impact and low-risk sport, injuries can still occur. The most common acute traumatic and overuse injuries are described. Most injuries can be prevented and treated conservatively. Cross-country skiing is a safe and physiologically ideal form of physical exercise, both recreationally and competitively.

Keywords: Adolescent, Young adult, Cross-Country Skiing, High-Performance, Physiology, Asthma, Injuries

Introduction

Long before becoming a leisure and sporting activity for industrial societies in temperate latitudes, cross-country skiing was the obligatory means of transportation for most ethnic groups living north of the Arctic Circle for millennia. In that geographical area, daily activities such as hunting, herding, and foraging are still based on skis. The first evidence of skis, in the form of cave engravings, dates back to 2,000 BC, although this human activity is believed to be at least 6,000 years old. The very harsh environment, particularly during the long freezing winters, forced many Arctic inhabitants to adopt a nomadic lifestyle to maximize the energy they can extract from prey and food and minimize any energy waste. From this perspective, the cost of locomotion could represent a substantial part of the energy balance and potentially limit migration time, hunting performance, and ultimately chances of survival. The technological evolution of skiing throughout history has allowed us to ski 2.6 times faster for the same metabolic power and, therefore, at less than half the cost of skis prior to the 6th century AD [1].

Currently, cross-country skiing is a sport that consists of traveling generally long distances on uneven terrain with slopes that may be steep, but not continuous. There are two techniques that allow progression on skis: the classic style, in which the skis move in parallel through tracks prepared by a snow machine that mark the route to follow; freestyle, in which any form of progression is allowed, although skiers usually propel themselves in a manner similar to that of speed skating (skater step or skating), pushing with the edge of the skis. Cross-country skiing is one of the most demanding endurance sports and is considered a low-injury risk sport that has many health benefits and few long-term risks. The main health problem for cross-country skiers is asthma [2].

There is some concern that cross-country skiing may be associated with a higher incidence of atrial fibrillation and bradyarrhythmias among athletes who have participated in numerous long-distance races for many years and performed well. However, mortality rates among cross-country skiers are lower than those of the general population [3]. Evidence suggests that cross-country skiing may reduce the risk of cardiovascular disease morbidity and mortality events and all-cause mortality via anti-inflammatory pathways, improvements in endothelial function and reduced levels of cardiovascular disease risk factors,

such as lipids, glucose, and blood pressure; and enhancement of cardiorespiratory fitness [4].

In this work, a narrative review of the physiology, asthma, and the most frequent injuries in high-performance adolescent and young adult cross-country skiers is carried out.

Physiology

High-performance adolescent and young adult cross-country skiers experience a range of physiological effects. These effects are a result of both the demands of the sport and the natural physiological adaptations that occur with regular training. Cross-country skiing involves considerable physiological challenges posed by combined upper and lower body exertion of varying intensity and duration. It is practiced in mountainous terrain with inclinations between +20 and -20%, at a maximum altitude of 1,800 meters above sea level, and in a cold environment, that sometimes reaches -20ºC. This sport has helped physiologists gain new knowledge about the limits of human performance and regulatory capacity [2].

Table 1 describes the main physiological effects on the respiratory system and oxygen consumption [5-10], the cardiovascular system and oxygen utilization [9-14], the musculoskeletal system and body composition [12-14], and the energy systems [8, 15-19] observed in high-performance adolescent and young adult cross-country skiers.

Table 1: Main physiological effects of cross-country skiing

Respiratory system and oxygen consumption
▪ Increase in static and dynamic lung volume
▪ Increases respiratory muscle strength (e.g., diaphragm)
▪ Increased airflow rates (5-20%)
▪ Increase in absolute and relative aerobic power (VO2 max)
Cardiovascular system and oxygen utilization
▪ Increased cardiac output
▪ Increased arterial caliber, especially in the arms
▪ Increased rate of blood flow to the muscles
▪ Increased hemoglobin and reticulocyte levels
▪ Increased extraction and rapid delivery of O2 to the muscles
▪ Decreases heart rate at rest
Musculoskeletal system and body composition
▪ Increased type 1 (slow twitch) muscle fibers in the legs, shoulders, and arms
▪ Increase in the size of muscle fibers (15-25%), especially in the arms
▪ Increased number of muscle capillaries, especially in the legs
▪ Increased bone mass density
▪ Increased strength, speed, endurance, and coordination, especially of the upper body
▪ Decrease in body fat percentage (both sexes) and increase in body mass index (especially in men)
▪ Improves the thermoregulatory adaptations
Energy systems
▪ Increased mitochondrial density in muscle fibers
▪ Increased aerobic energy production in the mitochondria
▪ Increased lipolysis and oxidation of medium-chain fatty acids
▪ Decrease in glycogenolysis, glycolysis, and deamination of AMP
▪ Increased release of lactate into the blood from the arm muscles
▪ Decreased release of lactate into the blood from the leg muscles
▪ Increased oxidative capacity of the muscles, especially the legs
▪ Increased anaerobic energy production derived from glycolysis and lactate reuse

It is important to note that these physiological effects can vary among individual skiers and depend on factors such as genetics, training regimen, nutrition, and overall health. Coaches and athletes must work together to optimize training programs and monitor these adaptations to support the skier's overall performance and well-being [2, 19-21].

Asthma

The main health problem for cross-country skiers is asthma. The prevalence of asthma in competitive adolescent and young adult cross-country skiers is 2 to 2.5 times higher and the age of onset is later compared to non-skiers. Several studies reported that asthma was underdiagnosed in skiers, as previously healthy skiers without a prior asthma diagnosis or medication use were frequently found to fulfill diagnostic criteria for asthma according to lung function tests. Asthma in cross-country skiers is mostly well-controlled and requires regular maintenance treatment. This disorder is not an obstacle to practicing this sport and there are high-performance athletes with competitive success who have asthma [22-24].

Conceptually, it is necessary to differentiate the so-called “asthma-like symptoms” which are defined as the presence of episodes of cough, abnormal shortness of breath, dyspnea, wheezing, or chest tightness in the last year, whether at rest, due to exertion or due to exposure to irritating agents; airway hyperreactivity to indirect stimuli, such as exercise, eucapnic voluntary hyperventilation, adenosine 5′-monophosphate, or hypo- or hypertonic aerosols; airway hyperreactivity to direct stimuli, such as methacholine, which is defined as the dose that causes a 20% decrease in forced expiratory volume in 1 second (FEV1); and ski asthma, which is defined by exercise-induced bronchoconstriction, with a decrease in FEV1 greater than 10% compared to the baseline before exercise, together with the presence of symptomatic asthma and the existence of bronchial hyperresponsiveness to methacholine. Airway hyperreactivity to indirect stimuli is considered more specific for asthma than hyperreactivity to a direct stimulus such as methacholine. Eucapnic voluntary hyperventilation is more sensitive than sport-specific field exercise or methacholine challenge and is the preferred test of the International Olympic Committee Medical Commission for the detection of exercise-induced bronchoconstriction [22, 25].

Cross-country skiing differs from most other sports in that the athletic effort of training and competition is intense and performed at low temperatures, involving the inhalation of large volumes of cold and dry air for several hours a week and several months of the year. It is known that physical exercise and inhalation of cold air can cause acute bronchoconstriction in susceptible people and that the combination of both can exacerbate the bronchoconstriction that occurs after exercise. During exercise, the airways respond with bronchodilation and bronchoconstriction after exercise or during exercise if it is very prolonged. It has been observed that there is a refractory period induced by an initial exercise challenge, the pre-competition warm-up, which provides protection against bronchoconstriction during competition. The variability in the onset of bronchial hyperreactivity and the lack of refractoriness implies a bronchoconstrictor dysfunction that is different from asthma [25-28].

Being a high-performance cross-country skier is an independent risk factor associated with developing asthma [29]. According to the meta-analysis, the prevalence of self-reported physician-diagnosed asthma in skiers was 21% (95% CI 14-28%). The onset age of asthma was higher in skiers than in non-skiers with asthma. The prevalence of asthma medication use was on average 23% (95% CI 19-26%) [22]. A study carried out among adolescent elite skiers has found that the prevalence of asthma is 27% (30% in women and 20% in men) with a mean age of 12 years at the onset of asthma, while the prevalence among their contemporaries was 19% and the age of onset was 8 years [30]. Other studies carried out with elite adolescent and young adult skiers have observed that 43-55% present bronchial hyperreactivity to any stimulus and 40% to the stimulus with methacholine, being twice as highly frequent in asymptomatic individuals than in symptomatic individuals. They have also observed that 28% present exercise-induced bronchial hyperreactivity, 14% to eucapnic voluntary hyperventilation, 9-28% to adenosine 5'-monophosphate, and 5% to mannitol [25-28].

The characteristic morphological changes in the bronchial mucosa in asthma are damage to the epithelium; the infiltration of eosinophils, lymphocytes, mast cells, and macrophages; remodeling of the airway, with thickening of the basement membrane and enlargement of the bronchial smooth muscle mass; and increased deposition of tenascin, an extracellular matrix protein, in the basement membrane. In adolescent cross-country skiers, compared with healthy controls, a mild to moderate degree of macroscopic inflammation of the proximal airways has been observed, with an increase in the percentage count of lymphocytes and mast cells in bronchoalveolar lavage fluid and blood samples endobronchial biopsy [31]. It has also been observed that the counts of T lymphocytes, macrophages, and eosinophils, as well as the expression of tenascin (measured through the thickness of the tenascin-specific immunoreactivity band in the basement membrane), were significantly higher compared to controls [32]. These inflammatory changes occurred independently of asthma symptoms, hyperreactivity, or atopy. Therefore, the researchers suggest that prolonged and repeated exposure of the airways to inadequately conditioned air in high-performance skiers may induce inflammation and remodeling of the airways, and may be the main factor in the pathogenesis of hyperreactivity to methacholine [27, 28, 31-33].

In fact, in winter athletes, bronchial hyperreactivity to methacholine is commonly used as objective evidence to justify the use of asthma medications [27, 28].

Regarding the management of this problem, is demonstrated that with medical supervision, peak flow rate monitoring, and appropriate use of bronchodilator inhalers, peak flow rates can be stabilized and even improved during cold-weather exercise. It has been suggested that using these measures should not restrict the practice of this sport in asthmatic adolescents and young adults [22-24, 34]. There has been no obvious beneficial effect of the use of inhaled budesonide (400 micrograms, twice daily) on cellular inflammation indices or tenascin expression in the bronchial mucosa, so more attention should be paid to reducing the airway stress rather than attempting pharmacological modulation of induced inflammatory changes [35].

Injuries

Cross-country skiing exercises most of the joints, muscles, and tendons of the body, which produces a complete workout of the musculoskeletal system. It is a sport with a low risk of injury, with its incidence estimated between 0.5 and 5.6 per 1,000 days of skiing. Of winter sports, cross-country skiing accounts for 1% of injuries reported to health insurance agencies, compared to 48% for downhill skiing, 23% for ice skating, 21% for snowboarding, and 7% for sled. This makes cross-country skiing a suitable activity for physical fitness and rehabilitation, as well as a safe recreational and competitive sport [36, 37].

The risks of injuries from accidents are largely due to the characteristics of this sport (variable terrain, speed, possible contacts). Other injury risk factors include training volume, training methods, competitive season period, technical equipment, and previous injuries [36, 38, 39].

The difficulties and variabilities of the terrain (icy or uneven terrain), speed (it can reach 70 km/h on descents), and contact with other skiers or obstacles can cause falls and collisions causing acute traumatic injuries. Acute injuries account for 25% of all injuries. They mainly affect the upper extremities (52%), followed by the lower extremities (28%), trunk (19%) and skull (1%). The most common are injuries to the ulnar collateral ligament of the metacarpophalangeal joint of the thumb caused by abduction and hyperextension of the same (“skier's thumb” or Stener injury) and injuries to the medial collateral ligament of the knee caused by impact on the outside of the knee when the knee is slightly flexed (the anterior cruciate ligament is often injured at the same time) [36-39].

Overuse injuries in cross-country skiing are common and often result from the repetitive nature of the sport. These injuries account for 75% of all injuries and typically develop gradually over time due to the strain and stress placed on specific muscles and joints. Chronic overuse injuries mainly affect the back (70%), followed by the lower extremities (20%) and the upper extremities (10%). The most common is pain in the lumbosacral region due to dysfunction or anomalies of the lumbosacral, sacroiliac, and lumbar spine joints [40-48]. Females are at greater risk of suffering from overuse injuries during the competitive season, as opposed to male athletes who are more likely to suffer from traumatic injuries [39].

Cross-country skiing takes place in snowy cold environments. Exposed skin can be at risk of frostbite, and skiers can also become hypothermic if not properly dressed for the conditions [36].

Table 2 describes the most common acute traumatic and chronic overuse injuries in cross-country skiing.

Table 2: Common injuries in cross-country skiing

Acute traumatic injuries
▪ Sprain or tear of the ulnar collateral ligament of the metacarpophalangeal joint of the thumb (Stener injury)
▪ Sprain or tear of the medial collateral ligament of the knee
▪ Sprain or tear of the anterior cruciate ligament of the knee
▪ Meniscus tears
▪ Muscle tears of the thigh and groin
▪ Shoulder dislocation
▪ Separation of the acromioclavicular joint
▪ Sprain or tear of the shoulder rotator cuff
▪ Achilles tendon rupture
▪ Sprain or tear of the ankle ligaments

▪ Subluxation, dislocation, or fracture of the lumbosacral-coccygeal joints (due to a fall in a sitting position)
Chronic overuse injuries
▪ Back pain in the lumbosacral region
▪ Back muscle strains or disc injuries
▪ Medial tibial stress syndrome (tibial periostitis)
▪ Achilles tendinopathy
▪ Tendinopathies in the scapular region, shoulder, elbow, or wrist
▪ Patellofemoral pain syndrome
▪ Iliotibial band syndrome
▪ Anterior compartment syndrome of the leg
▪ Stress fractures in the lower extremities (tibia, metatarsals)
▪ Osteoarthritis (metatarsophalangeal of the big toe, patellofemoral, hip)

Most of these injuries can be treated conservatively and some can be prevented. The main measures for its prevention are: performing preseason exercises that improve strength, balance, coordination, muscle flexibility, and agility; performing exercises targeting the mid-thoracic spine; acquiring adequate technical preparation and training; performing a correct warm-up and stretch before skiing; increasing the intensity and duration of skiing gradually to allow the body to adapt to the demands; learning how to fall; using sports equipment (skis, bindings, boots, and poles) in good condition, properly sized and adjusted to body; dressing in layers to stay warm and dry; resting and recovering sufficiently between ski sessions; participate in other physical activities besides cross-country skiing [36, 38, 39, 49, 50].

Conclusion

Regardless of the asthma and injuries associated with the sport, cross-country skiing is a safe and physiologically ideal form of physical exercise, both recreationally and competitively.

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