Effects of Skiing Intervention on Cardiopulmonary Function and Metabolic Indicators in Middle-aged and Elderly Adults

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Abstract

With the ongoing progression of population aging, declining cardiorespiratory endurance and dysregulated glucose-lipid metabolism have emerged as critical threats to the health of middle-aged and elderly populations. Skiing, as an outdoor fitness activity conducted under cold conditions, combines both aerobic and anaerobic metabolic characteristics and exerts unique stimulation and regulatory effects on the cardiopulmonary system and metabolic function. This paper presents a systematic review of the intervention effects and underlying physiological mechanisms of skiing on cardiorespiratory endurance and metabolic indicators in middle-aged and elderly adults. Multiple studies have demonstrated that skiing can effectively increase maximal oxygen uptake (VO_2max), reduce resting heart rate and systolic blood pressure, enhance cardiac output, and improve vital capacity. Concurrently, skiing regulates glucose and lipid metabolism by lowering triglycerides (TG), total cholesterol (TC), and low-density lipoprotein cholesterol (LDL-C), increasing high-density lipoprotein cholesterol (HDL-C), and improving insulin sensitivity and vascular endothelial function. The underlying mechanisms involve the “vascular gymnastics” effect induced by cold stimulation, the alternating pattern of aerobic and anaerobic metabolism, and the activation of basal metabolic rate under cold conditions. It is recommended that middle-aged and elderly adults engage in skiing-based fitness activities under scientific guidance to optimize cardiopulmonary and metabolic health.

Keywords

Skiing, Middle-aged and elderly adults, Cardiopulmonary function, Metabolic indicators, Intervention effects

Introduction

As population aging continues to deepen in China, the health status of middle-aged and elderly adults has drawn increasing societal concern [1]. According to data from the National Bureau of Statistics, the proportion of the population aged 65 and above in China reached 15.4% in 2023, with the aging trend accelerating continuously. Cardiovascular disease has become the leading threat to the health of middle-aged and elderly populations, while the incidence of metabolic diseases such as disorders of glucose and lipid metabolism has been rising annually. Declining cardiorespiratory endurance and deteriorating metabolic indicators are two core manifestations of health decline in middle-aged and elderly populations. These two factors are intertwined and mutually reinforcing. The decline in cardiorespiratory endurance leads to diminished aerobic metabolic capacity, restricting the efficiency of glucose and lipid metabolism. Metabolic disorders exacerbate vascular wall damage, thereby impairing cardiovascular function. A World Health Organization report indicates that regular exercise can reduce the risk of cardiovascular disease by approximately 30.0% and significantly ameliorate metabolic disorders.

However, constrained by multiple factors such as physiological decline and lack of exercise habits, the participation rate in daily fitness activities among middle-aged and elderly adults remains low. In particular, cold regions suffer from scarce outdoor fitness resources and monotonous exercise modalities during winter, leading to the continuous deterioration of cardiorespiratory endurance and metabolic health. How to effectively optimize the cardiorespiratory endurance and metabolic health of middle-aged and elderly

populations has become a key issue in the fields of public health and exercise science [2].

Exercise intervention has been widely recognized as an important approach to optimizing cardiorespiratory endurance and metabolic health in middle-aged and elderly adults. Regular aerobic exercise can effectively increase VO_2max, optimize cardiovascular function, and regulate blood lipid metabolism. However, the intervention effects of conventional aerobic exercise (e.g., walking, jogging) are limited by monotonous exercise intensity and insufficient environmental stimulation. Skiing, as an outdoor winter fitness activity performed under cold conditions, possesses both aerobic and anaerobic metabolic characteristics. Its exercise load exhibits intermittent fluctuations in accordance with terrain undulations. This provides greater intensity and dimensional stimulation to the cardiopulmonary system and metabolic function than conventional single-modality aerobic exercise.

In recent years, a series of empirical investigations on winter sports and the health of middle-aged and elderly adults has been conducted in academia. Its exercise load exhibits intermittent fluctuations in accordance with terrain undulations. This provides greater intensity and dimensional stimulation to the cardiopulmonary system and metabolic function than conventional single-modality aerobic exercise.

Empirical research on the effects of winter swimming on cardiopulmonary function in the elderly was conducted, concluding that winter swimming could effectively optimize cardiorespiratory endurance. Analysis of 40 middle-aged and elderly winter swimmers revealed that winter swimming could improve cardiovascular function and blood lipid levels. It was found that HDL-C and cardiac output in the winter swimming group of elderly adults were significantly higher than those in the control group. Scientific guidance strategies for speed skating exercise among middle-aged and elderly adults were proposed. At the meta-analytic level, it was verified that exercise interventions could improve blood lipid levels in middle-aged and elderly populations. A 36-week trial was conducted demonstrating that exercise interventions could simultaneously optimize cardiorespiratory endurance and metabolic indicators.

Building upon these findings, this paper conducts a systematic review of the intervention effects of skiing on cardiorespiratory endurance and metabolic indicators in middle-aged and elderly adults, and analyzes the physiological mechanisms. It also proposes practical recommendations to provide theoretical support for the development of scientifically grounded skiing-based fitness programs for middle-aged and elderly populations.

Effects of skiing on cardiopulmonary function in middle-aged and elderly adults

Effects on maximal oxygen uptake

Maximal oxygen uptake (VO_2max) is the core parameter for assessing the body's aerobic metabolic capacity and cardiorespiratory endurance. It gradually declines with age and serves as a key indicator for evaluating the cardiopulmonary health of middle-aged and elderly adults. Research indicates that after the age of 30, VO_2max declines by approximately 10.0% per decade, reaching only 60.0%-70.0% of youthful levels by age 60. This decline in aerobic metabolic capacity directly restricts daily activity endurance and independent living ability. One study selected 78 sedentary women aged 55-64 years old and conducted a 36-week randomized controlled trial. The results demonstrated that exercise modalities characterized by rhythmic variation and load fluctuation could effectively increase VO_2max and optimize cardiorespiratory endurance. The continuous pushing and turning movements in skiing generate intermittent load variations. These variations are similar to the rhythmic exercise pattern identified in that study. This facilitates the adaptive alternation of the cardiopulmonary system across different metabolic levels [3].

VO_2max in long-term winter swimmers was significantly higher than that in non-exercising peers, with notable improvements in vital capacity and maximal voluntary ventilation. Winter swimming and skiing are both winter sports conducted under cold conditions. The low-temperature environment requires the body to maintain thermal homeostasis while simultaneously engaging in physical activity. The superimposed effect results in a higher cardiopulmonary

load than exercise at normal temperatures, thereby more effectively activating adaptive changes in aerobic metabolism.

Effects on cardiovascular function

Declining cardiovascular function is a critical health concern for middle-aged and elderly populations, manifested as decreased myocardial contractility, reduced vascular elasticity, and elevated blood pressure. An analysis of 40 middle-aged and elderly winter swimmers revealed that winter swimming significantly reduced resting heart rate and systolic blood pressure while optimizing myocardial oxygen supply efficiency. Cold-water stimulation causes the cutaneous blood vessels to undergo rapid constriction followed by dilation, constituting a "vascular gymnastics" effect. Repeated training enhances the elasticity of the vascular wall and microcirculatory function, thereby contributing to the maintenance of normal blood pressure levels.

Cardiac output in the winter swimming group of elderly adults was significantly higher than that in the control group ($p<0.01$), and resting blood pressure was significantly lower. Cardiovascular function indicators in elderly adults who engaged in winter sports were also superior to those of ordinary elderly individuals, further corroborating the positive effects of cold-environment exercise on cardiovascular health [4].

Effects on pulmonary function

Typically, declining pulmonary function is primarily characterized by reduced vital capacity, decreased maximal voluntary ventilation, and weakened respiratory muscle strength. Notably, inhalation of cold air stimulates the respiratory tract, promoting deeper and faster breathing and increasing pulmonary ventilation. Both vital capacity and maximal voluntary ventilation in elderly winter swimmers were significantly higher than those in age-matched controls. Similarly, skiing exercise, with its intermittent high-intensity bouts and cold-air exposure, may further enhance respiratory muscle strength and endurance. The extensive pushing and turning movements in skiing require sustained engagement of the core muscles, with enhanced abdominal breathing and increased amplitude of diaphragmatic movement. This thereby contributes to the maintenance and optimization of pulmonary function [5].

Effects of skiing on metabolic indicators in middle-aged and elderly adults

Effects on glucose metabolism

Disordered glucose metabolism is a common problem in middle-aged and elderly populations, manifested as worsening insulin resistance and declining blood glucose regulation capacity, constituting a precursor to type 2 diabetes. Epidemiological surveys indicate that the prevalence of prediabetes among adults aged 45 and above in China has exceeded 35.0%, with glucose metabolism disorders becoming a major threat to the health of middle-aged and elderly populations. Exercise under cold conditions can optimize glucose metabolism through multiple pathways: Cold stimulation promotes increased thermogenesis, activates brown adipose tissue, and enhances glucose utilization. The alternating pattern of aerobic and anaerobic metabolism inherent in skiing can optimize skeletal muscle GLUT4 expression and enhance glucose transport capacity. Research revealed that glucose homeostasis indicators in the winter swimming group of middle-aged and elderly adults were superior to those in the control group, with improved insulin sensitivity. Regular exercise in cold environments, by enhancing skeletal muscle glucose transport capacity and improving insulin signal transduction, can effectively optimize glucose metabolic status [6].

Effects on lipid metabolism

Abnormal lipid metabolism is a major risk factor for cardiovascular disease in middle-aged and elderly populations, manifested as elevated TC, TG, and LDL-C, and decreased HDL-C. A meta-analysis has demonstrated that exercise interventions could significantly reduce TG and LDL-C and increase HDL-C in middle-aged and elderly adults. Exercise intensity and duration are important factors influencing the magnitude of blood lipid improvement. Another meta-analysis of 13 RCTs (826 participants) further verified that moderate-intensity aerobic exercise could effectively lower TC, TG, and LDL-C and raise HDL-C, with statistically significant effect sizes.

Blood lipid indicators in elderly winter swimmers were tested, revealing that HDL-C in the winter swimming group was significantly higher than that in the control group ($p<0.01$), while TG and LDL-C were

significantly reduced. The improvement in lipid metabolism associated with cold-environment exercise may be related to multiple factors. These include cold stimulation promoting lipolysis and fat catabolism, exercise energy expenditure in cold environments being 3.0%-7.0% higher than at normal temperatures, and an increased proportion of fat-derived energy supply. During skiing, the pushing and turning movements cause anaerobic and aerobic metabolism to alternate. This repeatedly activates lipid metabolism, and the improvement effect may surpass that of single-modality aerobic exercise [7].

Effects on endothelial function and vascular health

Vascular endothelial function is an important indicator for assessing vascular health and the risk of atherosclerosis. Plasma endothelin (ET) in winter-swimming middle-aged and elderly adults was significantly reduced, while nitric oxide (NO) content and Nitric oxide synthase (NOS) activity were increased, and the NO/ET ratio was improved. This indicates that regular exercise in cold environments can optimize vascular endothelial endocrine function. The mechanisms by which skiing improves endothelial function may involve cold stimulation, which induces stress adaptation in endothelial cells and enhances NO synthesis capacity. Intermittent exercise loads promote fluctuations in blood flow shear stress and activate endothelial cell repair mechanisms. Optimization of blood lipid levels also indirectly reduces lipid deposition in the vascular wall [8].

Physiological mechanism analysis

The intervention effects of skiing on cardiorespiratory endurance and metabolic indicators in middle-aged and elderly populations involve a triad of physiological mechanisms. These include the cold stimulation effect, the alternating pattern of aerobic and anaerobic metabolism, and skeletal muscle adaptive changes.

The “vascular gymnastics” effect induced by cold stimulation is the core mechanism distinguishing skiing from conventional aerobic exercise. Low temperatures cause periodic constriction and dilation of cutaneous blood vessels, effectively enhancing the elasticity of the vascular wall and improving microcirculation. Cold exposure also promotes sympathetic nerve excitation, accelerates heart rate, increases cardiac output, activates brown adipose tissue, elevates the basal metabolic rate by 3.0%-7.0%, and increases energy expenditure and fat mobilization [9].

The alternating pattern of aerobic and anaerobic metabolism is a unique exercise characteristic of skiing. Gentle gliding primarily relies on aerobic metabolism (heart rate at 60.0%-75.0% of maximum heart rate), while turning and braking rely on anaerobic metabolism (heart rate at 80.0%-95.0%). The intermittent load variation causes the cardiopulmonary system to switch alternately between different metabolic modes, thereby contributing to the comprehensive elevation of VO_2max. Skeletal muscle adaptive changes represent an important pathway through which skiing improves metabolism. Skiing requires the coordinated participation of multiple muscle groups throughout the body. Pushing activates the gluteus maximus and quadriceps femoris, and turning engages the core muscles. Braking stimulates the calf muscles. Long-term training can optimize skeletal muscle capillary density, mitochondrial content, and GLUT4 expression. This enhances aerobic metabolic capacity and glucose uptake capacity, and consequently improves glucose and lipid metabolism [10].

Conclusion

(1) Skiing can effectively optimize cardiopulmonary function in middle-aged and elderly populations. It increases VO_2max, reduces both resting heart rate and systolic blood pressure. It also enhances cardiac output, and improves vital capacity and maximal voluntary ventilation. The underlying mechanisms primarily involve the “vascular gymnastics” effect induced by cold stimulation. They also involve the multidimensional stimulation of the cardiopulmonary system through the alternating pattern of aerobic and anaerobic metabolism.

(2) Skiing can significantly improve metabolic indicators in middle-aged and elderly populations. It does so by lowering TG, TC, and LDL-C, increasing HDL-C, and improving insulin sensitivity and vascular endothelial function. The mechanisms encompass cold stimulation activating the basal metabolic rate, increasing the proportion of fat-derived energy supply, and enhancing skeletal muscle glucose uptake capacity.

(3) Improvements in cardiopulmonary function and metabolic indicators exhibit synergistic effects, forming a positive feedback loop that jointly delays the progression of health decline in middle-aged and elderly populations. Enhanced cardiorespiratory endurance improves tissue oxygenation, promoting glucose and lipid metabolic efficiency. Optimized metabolic indicators reduce the burden on the vascular wall, creating favorable conditions for further improvement of cardiopulmonary function. The mutual reinforcement and cyclical enhancement of these two dimensions render the health benefits of skiing for middle-aged and elderly populations superior to those of single-dimensional intervention approaches.

Practical recommendations

(1) Gradual progression and scientific assessment. Prior to participating in skiing, cardiopulmonary function assessment should be conducted to exclude potential risks. During the initial phase, gently sloped trails and low-intensity cross-country skiing should be selected, with intensity and duration gradually increased.

(2) Emphasis on warm-up preparation and thermal protection. In cold environments, adequate warm-up of 15-20 minutes should be performed to activate the lower limb and core muscle groups. Attention should be paid to keeping the hands, feet, and face warm, with brief rewarming breaks taken after each hour of skiing.

(3) Adherence to regular exercise. It is recommended to ski 2-3 times per week, 60-120 minutes per session, with the heart rate maintained at 60.0%-75.0% of maximum heart rate. Exercise prescriptions should follow the principle of individualization, with the starting intensity determined based on baseline cardiorespiratory endurance levels and gradually increased to an appropriate load. During the non-snow season, physical fitness reserves should be maintained through activities such as walking and swimming to ensure the continuity of exercise intervention.

Research outlook

At present, overall research on the effects of skiing on cardiopulmonary and metabolic indicators in middle-aged and elderly adults remains primarily based on indirect evidence (e.g., winter swimming, ice skating). However, direct RCTs using skiing as the intervention modality are still scarce. Small sample sizes and short intervention periods typically constrain the reliability of the evidence. Future research should conduct rigorous large-sample, multi-center skiing intervention RCTs. It should also compare the differential effects of various skiing types and intensities, and explore the interaction effects between cold stimulation and exercise load. It should further incorporate molecular biological indicators to elucidate deeper mechanisms. These efforts will ultimately provide more robust empirical evidence for the development of scientifically grounded skiing-based fitness programs for middle-aged and elderly adults.

Funding

This work was not supported by any funds.

Acknowledgements

The author would like to show sincere thanks to those te chniques who have contributed to this research.

Conflicts of Interest

The author declares no conflict of interest.

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