

ABSTRACT

Cross-country skiing has been of great interest for exercise physiologists during the last century and is regarded as one of the most demanding endurance sports. Of special interest is that the athletes have extraordinary high aerobic power and that both upper and lower body muscles are involved to various degrees in the different skiing techniques. The overall objective of the present thesis has been to examine and possibly extend the understanding of the physiology in cross-country skiing. In addition, elite cross-country skiers with highly trained arms and leg muscles enabled us to study some more general physiological questions. Eight articles are included in the thesis, divided into three major parts: 1) Contribution of the upper body in cross-country skiing (*Study I-III*), 2) Lung function (*Study IV-V*) and 3) Oxygen delivery and oxygen uptake (*Study VI-VIII*). The biomechanical data in *Study I* revealed that pole force, in contrast to poling frequency, is related to double poling (DP) velocity and is influenced by specific muscle activation patterns and a specific characteristic flexion-extension pattern in the elbow, hip and ankle joints with the angle minima occurring around the peak pole force. Moreover, that the muscles during DP are engaged in a sequential order starting with trunk and hip flexors, followed by shoulder and elbow extensors. Finally, that the best skiers use a special technical strategy with specific characteristics related to DP velocity. *Study II and III* demonstrated that specific DP training has a substantial effect on DP performance and improvements in DP performance were related to biomechanical as well as physiological parameters, shown in *Study III* by a parallel muscle adaptation in factors of importance for production of force as well as endurance and a bilateral transformation of MHC isoforms towards MHC IIA isoform. *Study IV* demonstrated that the measured lung function variables in elite skiers are only about 5-20% higher compared to sedentary persons, supporting the notion of a substantially larger trainability of cardiovascular and metabolic as compared to pulmonary functions. Furthermore, by using pulse oximetry, elite c.c. skiers are able to maintain their arterial O₂ saturation fairly well during submaximal exercise. During exhaustive exercise using diagonal skiing, double poling and running, the degree of desaturation was relatively low and less than what have earlier been reported in some highly trained endurance athletes. Furthermore, the ventilatory response was different in the exercise modes examined. These data were supported by invasive results from *Study V* performed with a similar cardiac output. Of special note was that the use of the DP technique demonstrated a better pulmonary gas exchange, and consequently a less degree of desaturation, compared to the other examined skiing techniques. Half of the reduction in the arterial saturation, during the different exercise modes during submaximal exercise, was accounted to the rightward-shift of the oxygen dissociation curve of the haemoglobin. In *Study VI* vascular conductance and blood pressure were adjusted to match O₂ delivery with the local tissue demand. Limb vascular conductance was linearly related to limb VO₂ during submaximal exercise. Moreover, the results support that maximal vasodilatory response during maximal whole body exercise has to be restrained. If not, the systemic vascular conductance would overwhelm the maximal pumping capacity of the heart and hypotension would ensue. In *Study VII*, the torso received ~80% of the cardiac output at rest and consumed more than 85% of the resting VO₂. During exercise the share of the systemic blood flow and the VO₂ was 25% or less which only represented a 3-fold elevation in absolute values, although cross-country skiing quite intensely involves all muscles of the torso. Altogether, these data point at a most efficient interaction between the torso muscles involved in force development for propulsion and the respiratory muscles, and the respiratory aerobic energy turnover was estimated to be ~5% of pulmonary oxygen uptake during moderate to intense exercise. Finally, in *Study VIII*, the oxygen extraction, in the arms but not in the legs, was closely related to the *in vivo* P₅₀ during arm exercise in the cross-country skiers with highly endurance trained arm and leg muscles and that the arms, for a given P₅₀ value, had a lower O₂ extraction and lower capillary muscle O₂ conductance values compared to the leg muscles. Since the conditions for the O₂ off-loading from the haemoglobin were similar in leg and arm muscles, the observed differences in maximal arm and leg O₂ extraction is suggested to be due to a higher diffusing distance and higher heterogeneity in the distribution of blood flow between and within muscles, shorter mean transit time, and smaller diffusing area in the arms compared to the leg muscles.

Key words: arterial O₂ saturation, blood flow, conductance, cross-country skiing, double poling, electromyography, ergometer, O₂ extraction, force, lung, muscle adaptation, oxygen uptake, oxygen cost, pulmonary gas exchange, training, upper body

ISBN 91-85910-95-3