



Physiological Background of Muscular Pain During Skiing and Delayed Muscle Soreness after Skiing

by
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During intensive skiing, at each turn, in particular towards the end of the turning steering phase, eccentric work of the lower limb muscles occurs (predominantly of the quadriceps femoris), which is the direct cause of damage within muscle cells. A few or more than ten hours after intensive physical effort the symptoms of delayed onset muscle soreness may appear, which is mainly a result of the micro-damage within the myocytes.

The following procedure can be proposed for prevention of muscle soreness for skiers: around a week before first day of skiing in the season, skiers should perform a series of intensive physical exercises involving eccentric contractions, thus inducing delayed muscular soreness. The exercises may involve for example: downhill running, preferably down a steep slope, running down stairs, deep knee bend jumps, deep knee bend jumps over an obstacle, jumping to the ground from a certain height, sit-ups on one or both feet, etc. The exercises should lead considerable local fatigue, in particular of the lower limb muscles, so that muscle soreness occurs on the second day, in particular in the frontal part of the thighs. After approximately two days the pain will alleviate, while after a week the strength of the muscles will return to its pre-exercise condition. This should considerably reduce, or even remove, delayed muscle soreness after skiing, which will not only help skiers use their time more effectively but will also be crucial to the skiers' safety..

Key words: DOMS, eccentric contractions, exercise physiology, skiing, pain prevention.

Introduction

As we all know, working human skeletal muscles may utilize aerobic and anaerobic energy processes, depending on the supply of oxygen. The use of these processes depends on the mutual relations between the possibilities of delivering O₂ to the working muscles and the current demand for oxygen.

The demand for oxygen in the muscles depends first and foremost on the intensity of physical effort. This relationship is directly proportional, i.e. the more intensive effort, the higher demand for oxygen. On the other hand, the amount of O₂ delivered to the muscles depends on the efficiency of the human body's mechanisms for supplying oxygen, i.e. mainly the respiratory system, the circulatory system and the oxygen capacity of the blood. Thus if these

mechanisms deliver a sufficient amount of oxygen to the muscles, the energy used for the work comes from aerobic processes. This is the case, for example, during long-lasting and low-intensity effort (for example jogging). If, on the other hand, the oxygen supply mechanisms are not able to deliver a sufficient amount of O₂, then the energy for the physical work must be supplied through anaerobic processes (for example sprint). However, most often, in many sport disciplines (notably team sports), due to the frequent changes in the exercise intensity, the body uses mixed energy sources, utilizing both anaerobic (e.g. start for the ball, fast change of the position), and aerobic processes (for example during breaks and phases of reduced activity).

The interrelations described above relate to any physical activity, i.e. also Alpine skiing. Depending

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on the work intensity, the muscles, in particular those of the lower limbs, utilize both aerobic and anaerobic energy processes. Aerobic reactions dominate mainly during large-radius turns on low-inclined slopes, while anaerobic processes during small-radius turns and skiing down steep slopes, when the intensity of muscle work increases radically.

The type of the energy-supplying biochemical processes taking place in the muscles determines the types of metabolites produced in the muscles during exercise. Aerobic reactions produce carbon dioxide and water, which are the final products of the Krebs cycle, while anaerobic reactions produce lactic acid, which is produced during anaerobic glycolysis.

Carbon dioxide and water, produced during aerobic (low intensity) exercises do not pose a problem from the point of view of the physical capacity. This is because CO₂ is removed from the body during gas exchange processes in the lungs, whereas the water is used by the body, which often suffers from water deficit during physical effort. This is not the case with the product of anaerobic processes, i.e. lactic acid, which is produced by myocytes during high-intensity muscle work. Lactic acid is one of the fundamental causes of fatigue, notably central fatigue, and blocks the possibilities of sourcing energy from glycolysis processes.

Referring the information presented above to the physical effort of a skier, one can conclude, that during technically proper skiing down a mild slope with the turns initiated by "edge changes", the muscles of a skier do not produce many acidic metabolites, which are the main cause of fatigue. Dynamic skiing down a steep slope causes an increase in the concentration of lactic acid in the muscle cells and blood, which can lead to a reduction in the capacity of the working muscles.

One can often hear opinions, that the muscular soreness felt during - and often for a few days after - intensive physical effort, is a result of muscle "acidity". In other words lactic acid is considered to be the main and direct cause of pain in fatigued muscles.

The paper is a communication regarding the most significant aspects of physiological background of muscular pain during and after skiing. The main aim of this study is to explain to skiers, other sportsmen and trainers, that the lactic acid is not the main reason of muscular soreness accompanied most physical activities and to propose exercise procedure, which should considerably reduce, or even remove

delayed muscle soreness after skiing. During this study the following questions were formulated:

- What is the main and direct cause of pain in working and fatigued muscles?
- What kind of physical work intensifies the pain?
- What should be done to alleviate the symptoms related to delayed muscle soreness?

Discussion

The statement, that lactic acid is the main reason of muscular pain is not confirmed by scientific research (Clarkson and Hubal 2002, Cleak and Eston 1992, Coudreuse 2004, Friden 1981, Lieber and Friden 2002, Schwane et al. 1983). This can be proved easily in view of the fact that injecting lactic acid directly into the veins or muscles does not cause muscle soreness. What is more, increased acidity of the muscles persists much longer than muscle soreness during exercise. It also has to be pointed that during the second or third day after physical effort, the concentration of lactic acid is not higher than under resting conditions, yet the soreness is still felt. This is what skiers experience, for example after the first day of the skiing season, particularly when they have not prepared themselves in physical terms. In such a case, aching muscles of the lower limbs not only make skiing difficult over the days that follow, but often also hamper normal movement, such as walking down stairs, doing a knee bend, etc.

In order to carry out a physiological analysis of the causes of muscular pain, one has to differentiate between sharp pain occurring during physical action and subsiding after it stops, and delayed onset of muscle soreness (DOMS), which occurs 6 to 12 hours after intensive physical action and usually persists for 2-3 days (Armstrong 1984, Byrnes and Clarkson 1986, Jones et al. 1986, Cleak and Eston 1992). There are numerous theories of potential etiology of delayed muscle soreness (Armstrong 1984, Cleak and Eston 1992, Gulick and Kimura 1996, Willoughby 1990). Many researchers have attempted to identify strategies for prevention of this kind of muscle soreness (Birk 1999, Claps 2000, Cleary 1995, Isabell et al. 1992, Johansson et al. 1999, Lightfoot et al. 1997, Nosaka and Newton 2002, Paddon-Jones and Quigley 1997, Rodenburg et al. 1994, Sharkey 1995, Vickers et al. 1997, Wessel and Wan 1994).

During skiing, the muscles of the lower limbs perform isometric contractions for a relatively long time (increased tension with no changes in the mus-

cle length), i.e. under conditions of deficient blood flow. This is because tense muscular cells (myocytes) put pressure on the blood vessels, causing local ischaemia, i.e. inadequate supply of oxygen and energy substances to the muscles and increased concentration of the effort metabolites, such as lactic acid, ammonia, phosphates, nucleotides. The main reason of muscles fatigue is increase of lactate and H^+ concentrations. It is very important, that skeletal muscles are capable of producing and releasing large amounts of lactate. The produce and release of lactate and H^+ involve transmembrane transport. This transport is mediated by MCT (monocarboxylate transporter) which is a membrane protein important for pH regulation (Brooks 2000, Brooks 2002, Juel 2001). Scientific researches show the significant influence of muscle content of proteins involved in lactate transport (MCT) and pH regulating mechanisms on work capacity mainly during supramaximal exercises. Monocarboxylate transporter expression is important for blood lactate and H^+ removal and in consequence for tolerance to muscle fatigue (Messonnier et al. 2007, Thomas et al. 2005). The reason for the training-induced increase in lactate concentration and H^+ release during exercise is a combination of an increased density of the lactate and hydrogen ion transporting systems, an improved blood flow and increased systemic lactate and H^+ clearance (Juel et al. 2004).

Modern skiing techniques (carving) cause a relatively long ischaemia of the working groups of muscles, which is caused by the longest possible weighting of the skis during turns and elimination of unweighting, during which tense muscles could be relaxed for a short time. Besides, during intensive skiing, at each turn, in particular towards the end of the turning steering phase, when the load is the highest, eccentric work occurs (increased tension combined with increased stretch), which is the direct cause of damage within muscle cells (Armstrong 1984, Brown et al. 1999, Cheung et al. 2003, Clarkson and Hubal 2002, Coudreuse et al. 2004, Friden et al. 1983, Friden et al. 1981, Friden and Lieber 1992, Lieber and Friden 2002, MacIntyre et al. 1995, McHugh et al. 1999). This is because tense myocytes are subjected to stretching forces. The higher skiing speed and smaller turning radius cause the higher stretching forces. Then, in particular the quadriceps femoris, counteracting the centrifugal force created during each turn and forcing the skier into the snow, are subject to intensive stretching forces. The damages

thus created and the abovementioned metabolites, seem to be the most important cause of muscular soreness, felt as sharp "burning" pain, which usually forces the skier to stop the action, or if it is possible, significantly reduce its intensity (reduce the speed or lengthen the turning radius).

A few or more than ten hours after intensive physical effort the symptoms of DOMS may appear, which is a result of the micro-damage within the myocytes (Cheung et al. 2003, Newham et al. 1987). The soreness is caused by inflammatory processes taking place within the damaged structure of the muscles, swelling of the muscular cells, impact of the products produced after muscular damage and the healing processes, which are aimed to restore the structure of the myocytes to their pre-damage condition (Cleak and Eston 1992, Coudreuse et al. 2004).

As it was mentioned above, mechanical damage of the muscles is related to the damage of the cell membrane. That the damage does exist is evidenced by the penetration of intracellular enzymes, such as creatine kinase and lactate dehydrogenase, into the blood (Byrne et al. 2004, Clarkson et al. 1986, Newham et al. 1986, Newham et al. 1983, Porzęcki et al. 2004, Sayers and Clarkson 2001, Sayers et al. 2000). These compounds are commonly recognized markers of muscular damage. This is because they have isoforms specific to skeletal muscles, which allows for differentiating micro damage occurring in this type of muscles from damages of e.g. the cardiac muscle. Besides, the amount of myoglobin increases in the blood plasma, which, being a counterpart of hemoglobin, is a muscle protein responsible for bonding and storing oxygen. Thus the presence of the abovementioned compounds in blood, which are normally contained inside muscular cells, is a proof that the myocytes are damaged, and the highest concentration of these substances in the blood plasma corresponds to the peak rigidity and soreness of the muscles (Clarkson et al. 1986, Clarkson and Ebbeling 1988, Schwane et al. 1983, Tiidus and Ianuzzo 1983).

The most intense DOMS is experienced following strenuous physical work based involving eccentric contractions (Cheung et al. 2003, McHugh et al. 1999). Skiers most often complain of pain in the extensors of the lower leg, i.e. predominantly of the quadriceps femoris. Similar pain may be caused for example by long-lasting downhill walking or running (Byrnes et al. 1985, Schwane et al. 1983). Mountain hikers suffer from more painful delayed muscle soreness after descending a mountain than

ascending it, although, as we know, energy consumption during uphill climbing is much higher due to the gravitation. This is because each step uphill is based on a concentric contraction of the quadriceps femoris (the muscle shortens), whereas each step downhill is based on the said eccentric contractions (the muscle stretches), which are the direct cause of the aforementioned micro-damage in the myocytes.

After a physical exercise which causes delayed muscle soreness, the strength and power of the muscles weaken considerably (Lieber et al. 1996, Smith 1992) and they are fully recovered only after approx 1-2 weeks (Cheung et al. 2003). Yet, for the 6-12 weeks that follow the muscle cells maintain increased resistance to reoccurring damage (Clarkson and Hubal 2002, Clarkson and Tremblay 1988, McHugh et al. 1999, Stupka et al. 2001). Therefore once DOMS subside, even despite similar or even much higher strain, the soreness will not reoccur or it will be much less intense.

The information presented above can be used by skiers, as they can organize their preparations for a longer skiing holiday in a more rational manner, in particular when they intend to make their first contact with the slope during the season. This applies in particular to amateur skiers not engaged in everyday physical activity, although it should also be used by professional sportsmen, especially after a long break in training (Cheung et al. 2003).

Conclusion

In order to avoid the adverse symptoms of muscular soreness, skiers should take into account the following information when preparing themselves for skiing:

- intensive muscle work involving eccentric contractions causes micro-damage in the inner structures of the muscle,

- after around 1-2 weeks the muscles recover their original strength and power,
- for 6-12 weeks the muscles will show a higher resistance to repeated damage and muscle soreness.

Summing up the information presented above, the following procedure can be proposed: around a week before skiing, skiers should perform a series of intensive physical exercises involving eccentric contractions, thus inducing delayed muscular soreness as a result of micro-damage within the quadriceps femoris. The exercises may involve for example downhill running, preferably down a steep slope, running down stairs, deep knee bend jumps, deep knee bend jumps over an obstacle (e.g. a bench), jumping to the ground from a certain height (e.g. from a chair, gym wall bars), sit-ups on one or both feet, etc. The skiers may end each exercise with adopting the downhill skiing position, as the structure of the movements during the exercises should resemble, as much as possible, the specific character of the action during skiing. Naturally, each series of exercises should be preceded by a suitable warm-up, and the strain adjusted to the physical capacity of the individual so that their motor system is not overstrained. Therefore it is absolutely necessary to increase the level of difficulty gradually. It should be stressed that the exercises should lead considerable local fatigue, in particular of the lower limb muscles, so that muscle soreness occurs on the second day, in particular in the frontal part of the thighs. After approximately two days the pain will alleviate, while after a week the strength of the muscles will return to its pre-exercise condition. This should considerably reduce, or even remove delayed muscle soreness after skiing, which will not only help skiers use their time more effectively and derive more pleasure from the first contact with the snow, but will also be crucial to the skiers' safety, which is one of the most important aspects of skiing.

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