PHYSICAL INACTIVITY IS A CAUSE AND PHYSICAL ACTIVITY IS A REMEDY FOR MAJOR PUBLIC HEALTH PROBLEMS

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Review
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Introduction

Firm scientific evidence shows that numerous diseases or precursors of diseases are more common in individuals that engage in little or no physical activity as compared with their regularly active counterparts. The number of these conditions has grown continuously during the past decades (Booth, Chakravarthy, Gordon, & Spangenburg, 2002; Table 1). The observed relationships between little or no physical activity and increased prevalence (existence) or incidence (appearance) of the diseases is not due to so called confounding factors such as age, sex, body fat, previous health, diet, smoking, alcohol consumption, education, or income.

Gradually epidemiological studies have provided stronger and stronger evidence that physical inactivity is a cause of developing these states of ill health. The criteria for this evidence are the constancy of the findings in different studies and populations, strength of the association between the level of physical activity and the risk of the disease, appropriate temporal sequence (inactivity predating the appearance of the disease), logical relationship between the level and change of level of inactivity/activity and the disease risk, and plausible and coherent explanations of the observed relationships. Studies on animals have provided further supporting evidence.

Why is physical inactivity deleterious for health?

The basic reason for the health-worsening and even health-damaging effects of physical inactivity is simply that **men (and women) are made to move.** They have been moving for the whole history of mankind except for the last tens of years. Physical activity has been and remains an essential biological stimulus that is needed to maintain the structures and functions of organs and organ systems to serve their

Table 1. Health conditions related to physical activity (PA) or inactivity (PIA) on the basis of published scientific evidence – (based on Booth et al., 2002)

Musculoskeletal conditions
Sarcopenia: p, m
Osteoporosis, falls, and related fractures: p, m, r
Osteoarthritis: m, p?
Rheumatoid arthritis: m
Low back pain: m, p
Neck pain: m
Injuries and posttraumatic/operative states: r
Cardiorespiratory conditions
Coronary heart disease: p. m, r
Congestive heart failure: m
Stroke: p, r
Peripheral arterial disease: m, p
Hypertension: m, p
Hyperlipidemia: p, m
Bronchial asthma: m
Chronic obstructive pulmonary disease: m
Metabolic conditions
Overweight and obesity: p, m
Type 1 diabetes mellitus: m
Type 2 diabetes mellitus: p, m
Metabolic syndrome: p, m
Gallstone disease: p? (PIA increases risk)
Cancer
Colon ca: p, r
Breast ca: p, r
Most other ca´s: r
Neurological and mental conditions
Cognitive decline (with ageing): m, p?
Alzheimer disease: m, p? (PIA may increase risk)
Several neurological diseases: m, r
Depression (mild, moderate): m, p?
Anxiety: m, p?
Other conditions
Fibromyalgia: m
Upper respiratory infections: p?
Duodenal ulcer: PIA may increase risk
Urinary incontinence: m
Chronic fatigue syndrome: m
Menopausal symptoms: m
Acute and chronic pain: m
Erectile dysfunction: PIA may increase risk
Smoking (addiction): PA may help in cessation
Sleep disturbances: m

Explanations: p = prevention; m = management; r = rehabilitation; ? = insufficient evidence

purpose. The stimulating effects of physical activity are mediated by gene expression, and the genes are thought to have adapted to a state of regular physical activity during the time our ancestors were habitually active hunter-gatherers (Booth et al., 2002). Their typical physical activities such as brisk walking for sustained periods caused increased loading to loco-motor, metabolic, cardio-respiratory, nervous, endocrine, and excretory organs, and repeating these activities led to adaptations in these organs to increase their tolerance to the load and various environmental conditions. If health is understood as energy and potential for survival, performance, and achievement in life in its physical, mental, and social domains, then most if not all of the adaptations caused by a moderate amount and intensity of physical activity are health-enhancing by increasing the structural strength and/or functional capacity of the corresponding organ. Many of the adaptations also decrease the risk of certain diseases or their precursors such as being overweight and obesity. Physical inactivity, lack of biological stimulus, causes the opposite effects and increases the risk of a number of states of ill health as shown in Table 1. Thus, the miracle-like effectiveness of physical activity for health is based on sound biological foundation.

The role of physical inactivity as a risk factor varies greatly for various diseases and between individuals. In general, physical inactivity is the more important as a risk factor the more central and unique role physical activity has for the maintenance of the structures and functions of the corresponding organ. Thus, physical inactivity is a very strong risk factor for developing muscle and bone loss in older people and of type II diabetes, but a less strong risk factor of e.g. coronary heart disease or cancer.

What is physical inactivity

Is physical inactivity a state of complete physical rest or can it include some activity, bodily movement produced by skeletal muscles that results in energy expenditure? Certainly physical inactivity or a sedentary state can include some muscular activity and the consequent changes in metabolic, regulatory and other functions. However, these are too little, short-lived or infrequent to give sufficient stimulus for the various organs to maintain their normal structures, functions and regulations. This means that physical inactivity is a different state for different organs and also for different people. Thus, for a young, fit person physical inactivity can include more activity than for an old person with weakened structures and limited functions. Physical inactivity is the lack of sufficiently strong contractions of the muscle to stimulate its rebuilding, lack of sufficiently increased metabolism to stimulate various metabolic and other regulations, lack of sufficient amount of skill-requiring movements to maintain the motor control of movements and so on. In exercise training this stimulatory level is called physiological overload.

Health-damaging effects of physical inactivity

Loss of muscle, strength and power. By age 50 most people will have lost about 10% of their muscle mass, and by age 70 they will have lost about 40%. Muscle strength is lost in about the same proportions or even more. Most atrophy is seen in fast twitch fibers, and therefore muscle power is greatly reduced. Muscle loss is seen especially in physically inactive individuals but also in persons who have been continuously physically active (Roth, Farrel, & Hurley, 2000; Roubenoff, 2001). Since the middle of the 1990´s the age-related loss of muscle mass, strength and function has been called **sarcopenia** in analogy to osteopenia. In one study moderate to severe sarcopenia (defined as muscle mass two standard deviations or more below the sex-specific mean for young adults) was found in 10% of women and 7% of men 60 years or older (Janssen, Heymsfield, & Ross, 2002).

Sarcopenia has several serious consequences (Roth et al., 2000; Roubenoff, 2001; Vandervoort & Symons, 2001). It leads to the impairment of physical function as indicated by difficulties to rise from a chair, climb stairs, generate sufficient gait speed e.g. on street crossing, and to maintain balance. Low muscle strength and poor balance are important risk factors for falls. Sarcopenia may lead to the fear of moving around and thus initiate a vicious circle that leads to progressively deteriorating function. The likelihood of functional impairment and disability was approximately two times greater in older men and three times greater in older women with moderate to severe sarcopenia as compared with subjects without this condition (Janssen et al., 2002). Lack of sufficient muscle strength causing pull and torsion in the bones accelerates bone loss and increases risk of osteoporosis. Sarcopenia means also a decrease of metabolically active muscle tissue and leads to increased fat mass without concomitant

change in body mass with ageing. Thus, confronted by a the rapidly increasing number of older people in the population, sarcopenia is a serious public health problem.

Several factors contribute to the loss of muscle mass and sarcopenia. A part of the motor neurons die with age resulting in a denervation of muscle fibers within the motor unit. These fibers will atrophy or die except in the case they are innervated by an adjacent motor neuron. The second factor contributing to the development of sarcopenia is the decreased rate of protein synthesis leading to decreased muscle mass and impaired muscle regeneration after injury or overload. The third factor is decreased concentration of several anabolic hormones. Also insufficient dietary intake of protein and/or energy may contribute to sarcopenia (Evans, 2000). Lack of physical activity, especially the lack of overload to the muscle, as in heavy lifting and resistance exercise, is definitively an important factor increasing and accelerating the development of sarcopenia (Roth et al., 2000; Roubenoff, 2001).

Osteoporosis and related fractures. Osteoporosis is characterised by low bone mass and microarchitectural deterioration of the bone tissue. The commonly used indicator of bone mass is areal bone mineral density (BMD). It accounts for 75 – 85% of the variance in ultimate bone firmness. The diagnostic criterion for osteoporosis is the BMD at least 2.5 standard deviations (SD) below the mean of young adult women. One SD is usually around 12 – 14% of a given BMD value.

Osteoporosis is usually symptomless and therefore it develops very often insidiously. Over the life span, women lose approximately half of their bone mass and men experience declines of approximately 30%, but there are great individual differences. Approximately 70% of women over 80 have osteoporosis. Bone loss increases the fragility of the bone and risk of fracture. Each reduction of 10 – 15% of bone mass doubles the fracture risk. The lifetime risk of having at least one fracture is approximately 32% for vertebral fracture and 16% for hip fracture. The fracture risk increases very rapidly with age after 70 –75 years (Ross, Santora, & Yates, 1999; Nevitt, 1999). In many populations the number of osteoporotic fractures is increasing rapidly due partly to the increasing number of old people, but the fracture incidence increases also in each older age group (Kannus, Niemi, Parkkari, Palvanen, Vuori, & Järvinen, 1999; Ross et al., 1999).

It is important to notice, that the proportion of fractures attributable to osteoporosis is not more than 28% for hip fractures and 25% for spine fractures in older women (Stone, Seeley, Lui, Cauley, Ensrud, Browner et al. 2003). Other factors, particularly falls, explain the rest of the risk. Although only about 5% of falls in older persons lead to fracture (Kannus et al., 1999), the high incidence of falls among elderly subjects makes falls a great hazard. Thus, prevention of osteoporotic fractures calls for measures that prevent osteoporosis, falls, and other risk factors of fractures. Prevention of these fractures is important because of their great number and the amount of disability and suffering, use of health care services, high costs, and excess mortality caused by them (Ross et al, 1999; Nevitt, 1999).

Physical inactivity can influence the risk of osteoporotic fractures by increasing the risk of osteoporosis and risk of falls. The risk of hip fracture is 20 – 40%, up to 55% higher in physically inactive as compared with active subjects (Joakimsen, Magnus, & Fonnebo, 1997; Gregg, Pereira, & Caspersen, 2000; Kujala, Kaprio, Kannus, Sarna, & Koskenvuo, 2000; Hoidrup, Sorensen, Stroger et al. 2001; Feskanich, Willett, & Colditz, 2002). The evidence is stronger in women than in men (Karlsson, 2002, 2004) and it is consistent only for hip fractures. A major part of the increased risk related to physical inactivity is likely due to the increased risk of falls and to a lesser extent to the increased risk of osteoporosis.

Quantitative information of the risk of osteoporosis and of falls caused by physical inactivity is scarce and to a large extent indirect. Complete physical inactivity such as bed rest and immobilisation in plaster cast leads to substantial and rapid bone loss (Krolner, Toft, Nielsen, & Tonevold, 1983). However, even modest physical activity seems to maintain the bone mass at a reasonable level as demonstrated e.g. by the only modestly lower (8%) hip BMD in the visually handicapped. Otherwise healthy women with severely limited abilities for brisk or more vigorous physical activities for most of their lives as compared with normal sighted women (Uusi-Rasi, Sievänen, Rinne, Oja, & Vuori, 2001). These findings, as well as the rather few epidemiological studies that have examined this issue (Ward, Lord, Williams, Anstey & Zivanovic, 1995, Uusi-Rasi, Sievänen, Vuori, Pasanen, Heinonen, & Vuori, 1998; Jakes, Khaw, Day, Bingham, Welch, Oakes et al., 2001; Pescatello, Murphy, Anderson,

Costanzo, Dulipsingh; & De Souza, 2002) indicate that low levels of physical activity in healthy ambulatory subjects is associated with slightly lower (up to about 5%, Vuori, 1996) bone mass, and may contribute to a modest degree to the risk of low bone mass and osteoporosis. However, physical inactivity may decrease bone firmness more than bone mass due to changes in the bone mass distribution (bone geometry). This effect is seen particularly in older subjects who may be at risk of osteoporosis (Uusi-Rasi, Sievänen, Pasanen, Oja, & Vuori, 2002). Physical inactivity may have the most critical role in increasing the risk of osteoporosis in subjects with high risk for this condition due to genetic and/or other factors.

Much attention has been paid to the peak bone mass concept meaning that the bone mass accrues rapidly in childhood and adolescence and reaches its peak at about 20 years of age or earlier. If the peak bone mass is large, there is more bone to be lost during the later life. The bone is most responsive to physical activity be-fore or at puberty (Kannus, Haapasalo, Sankelo, Sievänen, Pasanen, Heinonen, Oja, & Vuori, 1995; Haapasalo, Kannus, Sievänen, Pasanen, Heinonen, Oja, & Vuori, 1998). Physical inactivity during these years could result in low peak bone mass, and it would not be possible to compensate for this handicap during the subsequent years. However, it is not known whether the high peak bone mass due to intensive physical activity (Vuori, 2001a) contributes to maintenance of sufficiently high bone density until old age in ordinarily active subjects. Currently there is limited evidence that physical inactivity in adolescence results in lower (Ward et al., 1995) and physical activity in higher (Puntila, Kröger, Lakka, Honkanen, & Tuppurainen, 1997) bone mineral density in middle age than activity and inactivity, respectively.

Physical inactivity contributes to the risk of osteoporotic fractures also by the increasing the risk of falls. The evidence for this is mainly indirect. Risk of falls is increased by factor such as low muscle strength, low range of motion, unstable gait, and poor balance that are negatively influenced by physical inactivity and positively by physical activity (American Geriatrics Society, 2001; Carter, Kannus, & Khan, 2001; NIH Consensus Panel, 2001; Tinetti, 2003). It is obvious that only part of the risk of falls attributable to these factors is due to physical inactivity *per se.*

Osteoarthritis. Osteoarthritis is a very common condition. In European subjects older than 60 years, clinically significant knee osteoarthritis is found in about 10% and hip osteoarthritis in about 5% (Petersson, 1996). Clinically osteoarthritis can be defined as a condition that combines the pathology of a disease with pain that occurs when the joint is used. The primary problem is the degeneration of the articular cartilage, although the joint and the adjacent tissues and their functions are also involved. The cause of the primary, most common form of osteoarthritis is not known, but genetic factors play an important role.

Physical inactivity can be related to the development and risk of osteoarthritis directly and indirectly. The joint structures, especially cartilage, need frequent dynamic loading in order to maintain the nutrition and the structure of the non-vascularised cartilage and functions of the adjacent tissues. Lack of physical activity in youth is hypothesised to lead to deficient development of the joint cartilage (Helminen, Hyttinen, Lammi, et al. 2000). Immobilisation of a joint even for a short period leads to detrimental, initially reversible but gradually irreversible effects in the joint cartilage. Continuous physical inactivity may lead also to decreased strength, proprioception, coordination and balance, and consequently to decreased joint stability, malalignments, and injuries. Furthermore, physical inactivity increases the risk of being overweight and obesity. All these factors increase the risk of osteoarthritis, particularly in the knee but also e.g. in the hip (Felson, Lawrence, Dieppe, Hirsch, Helmick, Jordan et al., 2000).

Low back pain. Pain, muscle tension and stiffness in the low back or lumbar region is experienced by 70 – 85% of all people at some time in life, and at any one time point 15 to 45% of the people in a population have these symptoms. In most cases the symptoms disappear in a few weeks, but their recurrence is common and in a smaller part the syndrome becomes chronic. Low back pain in various forms is one of the leading causes of absence from work (Andersson, 1999). All this data indicates the great public health significance of low back pain. The pathophysiology of the syndrome is poorly understood, and in about 85% of the cases no pathological findings are recognisable. One mechanism seems to be that the pain originates from tissue injury or inflammation that cause irritation, nociception. This in turn leads to muscular tension in order to decrease the movements that cause pain.

Currently there is no clear evidence indicating that physical inactivity would increase the risk of low back pain in previously asymptomatic adult subjects (Hartvigsen, Leboeuf-Yde, Lings, & Corder, 2000; Vuori, 2001a; Picavet & Schuit, 2003; Wedderkopp, Leboeuf-Yde, Andersen, Froberg, & Steen Hansen, 2003). In low back pain patients physical inactivity seems to be detrimental as compared to being active (Van Tulder, Malmivaara, Esmail, & Koes, 2000; Taimela, Takala, Asklof, Seppala, & Parviainen, 2000; Karjalainen, Malmivaara, Van Tulder, Roine, Jauhiainen, Hurri, & Koes, 2001). In school-aged children low back pain has been found to be increasing (Hakala, Rimpelä, Salminen et al., 2002). The role of muscle strength and lack of regular physical activity is obscure, but the symptoms are positively related to the amount of sitting in school (Salminen, Erkintalo, Pentti et al. 1999).

Overweight and obesity. The health consequences of overweight and obesity, increased risk of several diseases, functional disabilities and psychosocial problems, are related to the amount of fat tissue (Vainio & Bianchini, 2002). Thus, the risk of most health problems is increased only slightly with small to moderate overweight but very significantly with increasing degrees of obesity. The most serious metabolic risks are associated with abdominal fat deposits. They can be assessed by the ratio of the circumference at the waist and hip, the waist-hip ratio or by just the waist circumference.

Obesity is currently a very serious health problem world-wide because of its multiple consequences and its high and increasing prevalence in most populations (WHO, 2000; Vainio & Bianchini, 2002). The size of the problem is demonstrated e.g. by the estimate that the direct costs of obesity account for about 7% of the national health care expenditures in the United States (Colditz, 1999). A very alarming phenomenon is the rapidly increasing prevalence of being overweight and obesity among children (Flegal, 1999; Kumanyika, Jeffery, Morabia, Ritenbaugh, & Antipatis, 2002). Furthermore, the overweight children have become heavier (Jolliffe, 2004).

The overwhelmingly most common cause of being overweight and obesity is excess energy intake in relation to energy expenditure. There is a continuing debate regarding the relative role of these two factors in the current obesity epidemic (Blair & Nichaman, 2002). It is obvious, however, that the need of energy expenditure at work, in transport, and in domestic chores has decreased, and the amount of energy expenditure in leisure time pursuits is modest at best and has remained stable or even decreased rather than increased in many countries (Vainio & Bianchini, 2002).

Thus, a major factor explaining the obesity epidemic is most likely the continued decline in daily energy expenditure that has not been matched by an equivalent reduction in energy intake. This claim is supported by consistent findings from cross-sectional population studies showing a negative relationship between the level of physical activity and indices of obesity (Vainio & Bianchini, 2002). A systematic review of prospective cohort studies and clinical trials found that in most, although not in all of them, a large volume of physical activity during follow-up was associated with less weight gain (Fogelholm & Kukkonen-Harjula, 2000; Vainio & Bianchini, 2002). A recent prospective study on a large cohort of women showed that sedentary behaviours, especially TV watching, were associated with significantly increased risk of developing obesity independently of exercise levels, whereas even light to moderate activity decreased the risk of obesity during six years of follow-up (Hu, Li, Colditz, Willett, & Manson, 2003). Also in children some studies have shown that TV watching and other sedentary pursuits increase the risk of developing excess weight (Cortmaker, Must, Sobol et al., 1996; Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; Robinson, 1999). However, two recent Danish cohort studies found that low levels of physical activity did not increase the development of obesity in men who were normal weight or obese in youth (Bak, Petersen, & Sörensen, 2004) or in man and women of originally normal weight (Petersen, Schnor, & Sörensen, 2004), but obesity decreased the levels of physical activity in all these groups. Thus, physical inactivity seems to have been the consequence rather than the cause of obesity in these populations.

Physical inactivity has important health consequences in relation to obesity not only by increasing the risk of this condition but also by increasing its health consequences, especially metabolic aberrations. This notion is supported by findings indicating that the risk of e.g. death from all causes, coronary heart disease and diabetes are higher in unfit or less physically active obese subjects than in their fit or physically active obese counterparts (Lee, Blair, & Jackson, 1999; Wei, Gibbons,

Kampert, Nichaman, & Blair, 2000; Stevens, Cai, Evenson et al., 2002). Thus, it may be better to be fat but fit than non-fat but unfit, but certainly it is best to be fit and non-fat.

Type 2 diabetes mellitus. Type 2 or adult onset diabetes is a common and rapidly increasing disease. Globally around 4 million deaths every year are attributable to complications of diabetes, and it decreases the life expectancy by approximately 15 years. Due to its complications such as degeneration of the retina leading to blindness, kidney disease, coronary heart disease, stroke, amputations of the limbs, problems during pregnancy, and congenital malformations, diabetes causes an enormous burden to health care services and costs. Diabetes is on the repid increase in most populations, and by 2030 the number of subjects with type 2 diabetes is predicted to be more than double as compared with the current figure (WHO, 2002).

Type 2 diabetes develops as a combination of genetic susceptibility and environmental factors, and its rate increases steeply with age. The most important environmental factors are obesity, sedentary lifestyle and diet rich in saturated fats. Pathophysiologically type 2 diabetes is characterised by a gradually developing resistance of the skeletal muscle and other tissues to the effect of insulin. As a consequence, the beta cells of the pancreas produce increased amounts of insulin. If this compensatory mechanism is sufficient, the resulting hyperinsulinemia maintains blood glucose levels within the normal range. However, in a large number of the subjects with insulin resistance, beta cells function gradually declines leading to relative insulin insufficiency and hyperglycaemic diabetic state (Boden, 2001).

Several prospective studies have provided evidence that physical inactivity increases the risk of developing type 2 diabetes by 20 – 70% (ACSM, 2000; Folsom, Kushi, & Hong, 2000; Okada, Hayashi, Tsumura, Suematsu, Endo, & Fujii, 2000; Wannamethee, Shaper, & Alberti, 2000; Hu, Manson, Stampfer, Colditz, Liu, Solomon, & Willett, 2001a; Hu, Stampfer, Solomon, Liu, Colditz, Speizer et al. 2001; Vuori, 2001b). Physical inactivity and low cardiorespiratory fitness also increase the risk of mortality in men with type 2 diabetes (Wei et al., 2000). The risk of diabetes increases with an increasing amount of physical inactivity, probably in a dose-response manner and independent of exercise levels. Thus, the risk of developing type 2 diabetes in clinically healthy women during 6 years of follow-up increased by 14% for each 2-hour/day increment in TV watching and by 7% for each 2-hour/day of sitting at work. In the women who watched TV or were sitting at work or away from home or driving more than 40 hours/week the relative risk of developing type 2 diabetes was increased by 70% and 48%, respectively, as compared with the women who used only a minimal amount of time in these pursuits (Hu et al., 2003).

Hypertension. Blood pressure is a measure of the force that the circulating blood exerts on the walls of the main arteries. High blood pressure levels damage the arteries that supply blood to the heart, brain, kidneys and elsewhere, producing various structural changes and ultimately to deteriorating function and damage of the corresponding organs. There is no sharp distinction between normal and elevated blood pressure, but the borderline and classes of hypertension are agreed among medical experts on the basis of findings from epidemiological studies. Currently the borderline between normal (satisfactory) and (mildly) elevated blood pressure is set at 140/90 mmHg (WHO, 1999).

Most adults have blood pressures that are higher than optimal for health, and there are at least 600-million hypertension sufferers worldwide. High blood pressure is estimated to cause 7.1 million deaths annually, and it is attributable to about two thirds of strokes and half of heart disease. Increasing consumption of unhealthy diet and sedentary lifestyle with the consequent increase of being overweight and obesity will lead to further increase of the prevalence of hypertension (WHO, 2002).

Over 95% of hypertension is so called primary or essential hypertension. The ultimate cause of the blood pressure elevation is not known. Risk factors for essential hypertension include genetic factors, high intake of salt, fat and alcohol, insulin resistance and hyperinsulinemia, being overweight and obesity, psychic stress, and physical inactivity. Increased sympathetic activity seems to be an important factor in the genesis of hypertension (Julius & Majahalme, 2000; Pickering, 1997; Carretero & Oparil, 2000).

In observational epidemiological studies low levels of physical activity have been associated with a higher blood pressure level and about 30% higher risk of developing hypertension (Haapanen, Miilunpalo, Vuori, Oja, & Pasanen,

1997; Fagard, 1999; Bassett, Fitzhugh, Crespo, King, & McLaughlin, 2002; Sobagwi, Mbanya, Unwin, Kengner, Fezeu, Minkoulou, Aspray, & Alberti, 2002). In one study a highly significant trend in blood pressure was found across quintiles of the objectively quantified physical activity level, the difference in the mean systolic/diastolic pressure between the top and the bottom quintile being 6.3/4.4 mmHg in men and 10.7/5.9 mmHg in women. These effects were independent of obesity and cardiovascular fitness (Wareham, Wong, Hennings, Mitchell, Rennie, Cruickshank, & Day, 2000). Low fitness is associated with about a 50% higher risk of developing hypertension as compared with subjects with high fitness (Blair, Goodyear, Gibbons, & Cooper, 1984).

Metabolic syndrome. The metabolic syndrome is a constellation of multiple hypertension, dyslipidemia, and diabetes risk factors that cluster together and increase the risk of type 2 diabetes, cardiovascular disease, and premature mortality (Timar, Sestier, & Levy, 2000; Lakka, Laaksonen, Lakka, Niskanen, Kumpusalo, Tuomilehto, & Salonen, 2002; Liu & Manson, 2002; Ninomiya, L'Italien, Criqui, Whyte, Gamst, & Chen, 2003). An individual is considered to have metabolic syndrome if three or more of the following are present: high blood pressure, high blood glucose, high plasma triglycerides, low HDL cholesterol, and high waist circumference. The syndrome is characterised by insulin resistance and is also known as the insulin resistance syndrome.

Metabolic syndrome is a common and increasingly prevalent disorder. Multiple factors contribute to the pathogenesis of the syndrome (Grundy, Hansen, Smith, Cleeman, Kahn et al., 2004), but obesity and sedentary lifestyle coupled with an unhealthy diet and still largely unknown genetic factors are obviously involved. The role of obesity is clearly demonstrated by the finding that metabolic syndrome was present in 4.6%, 22.4%, and 59.6% of normal-weight, overweight and obese US men, and a similar distribution was observed in women (Park, Zhu, Palaniappan, Heshka, Carnethon, & Heymsfield, 2003).

Physical inactivity is associated with a substantially increased risk of the metabolic syndrome (Laaksonen, Lakka, Salonen, Niskanen, Rauramaa, & Lakka, 2002; Park et al., 2003), and this association was still stronger regarding cardiorespiratory fitness (Laaksonen et al., 2002). The role of physical inactivity in the genesis of metabolic syndrome is seen already in young adults as a positive relationship between hours of inactivity and the level and number of the metabolic risk factors constituting the syndrome (Gustat, Srinivasan, Elkasabany, & Berenson, 2002). The importance of physical inactivity in the pathophysiology of metabolic syndrome is based on the central role of skeletal muscle in the carbohydrate and lipid metabolism (Helge, Kriketos, & Storlien, 1998).

Coronary heart disease. Coronary or ischaemic heart disease is characterised by gradual obliteration of the arteries that nourish the heart muscle. This leads variably to gradual impairment of the pump function of the heart, symptoms at effort, and/or a fatal or non-fatal heart attack due to occlusion of a coronary artery or development of electrical instability. Annually coronary heart disease leads to about 7.2 million deaths and to more than 10 million heart attacks in the world. The high prevalence and increasing rates of coronary heart disease in many countries can be ascribed to a large extent to three factors: consumption of an unhealthy diet, lack of physical activity, and tobacco smoking (WHO, 2002). Also many genetic and environmental factors contribute in various degrees and ways to the development of coronary heart disease (Grundy, 1999).

The risk of coronary heart disease is 30 to 50% higher in physically inactive as compared with at least moderately active subjects. This association is seen in men and women and in various age groups (Kohl, 2001; Williams, 2001; Thompson, Buchner, Pina, Balady, Williams, Marcus et al., 2003), but the size of the risk for individuals and populations varies according to the presence and absence of other factors influencing the risk (Schnor, Jensen, Scharling, & Nordestgaard, 2002). Very importantly, a decrease or increase of physical activity is followed by an increase and decrease, respectively, of the risk of developing the disease (Paffenbarger, Hyde, Wing, Lee, Dexter, & Kampert, 1993; Lissner, Bengtsson, Björkelund, & Wedel, 1996; Wannamethee & Shaper, 1998; Sherman, D´Agostino, Silbershatz, & Kannel, 1999; Blair, Cheng, & Holder, 2001). Corresponding but even stronger associations have been found between physical (aerobic) fitness and risk of coronary heart disease (Blair et al., 2001; Williams, 2001) as well as between the change of fitness and change of coronary heart disease mortality or morbidity during the follow-up time (Blair et al., 2001).

Cerebrovascular disease (stroke). Stroke is a heterogeneous disorder that includes ischemic stroke (about 75% of cases), intracerebral hemorrhage (about 15%) and subarachnoidal hemorrhage (about 10%). They share only partly the same risk factors. An ischemic or thrombotic stroke is caused by a clot formation (atherosclerosis) and it has the same risk factors as coronary heart disease. A hemorrhagic stroke is a bleeding event and one of the main risk factors is high blood pressure (Tegos, Kalodiki, Daskalopoulou, & Nicolaides, 2000). Stroke is the third leading cause of death world-wide accounting for about 5.5 million deaths annually. In addition, stroke is the leading cause of disability in developed countries (De Freitas & Bogousslavsky, 2001; WHO, 2002; Sacco, Wolf, & Gorelick, 1999).

The role of physical inactivity as a risk factor of stroke is demonstrated in more than 20 large studies, 5/6 of them longitudinal studies with lengthy follow up, showing significant negative association between physical activity and risk of stroke (Kohl, 2001; Vainio & Bianchini, 2002; Kurl, Laukkanen, Rauramaa, Lakka, Sivenius, & Salonen, 2003). This association is seen particularly in the studies of higher quality (Batty & Lee, 2002). Corresponding negative association has been observed also between aerobic fitness and risk of stroke (Lee & Blair, 2002a, b). Current evidence is sufficient to include physical inactivity as one of the risk factors of stroke (Gorelick, Sacco, Smith, Alberts, Mustone-Alexander, Rader et al., 1999; Sacco, 1999; Tegos et al., 2000; Goldstein, Adams, Becker, Furberg, Gorelick, Hademenos et al., 2001; Hu, Stampfer, Colditz, Ascherio, Rexrode, Willett, & Manson, 2000; Hu et al., 2001b; Rodriquez, Sacco, Sciacca, Boden-Albala, Homma, & Di Tullio, 2002). On average a 15 – 30% higher risk has been observed in inactive subjects, men and women of various ages, as compared with their physically active counterparts.

Peripheral vascular disease. Atherosclerosis can affect also peripheral, especially lower leg arteries. In part of the subjects the decreased blood flow causes pain in movement, especially in walking. The pain forces the subject to stop the activity for a while, therefore the condition is called claudicatio intermittens. The prevalence of atherosclerosis of the leg arteries is high, about 20% in the population older than 70 years. However, only 15 – 40% of these subjects suffer from claudication (Stewart, Hiatt, Regensteiner, & Hirsch, 2002). The risk factors of this disease are the same as those for other atherosclerotic diseases, and e.g. coronary heart disease and claudicatio intermittens occur often in the same individuals. There is, however, only limited evidence that physical inactivity increases the risk of peripheral arterial disease (Housley, Leng, Donnan, & Fowkes, 1993; Engström, Ögren, Hedblad et al., 2001). This may be due to the fact that locally lower leg arteries are exposed to the effect of most physical activity, and even a small amount of physical activity may influence the blood flow and eventual other factors sufficiently to prevent the development of obliterating atherosclerosis.

Cancer. Cancer is a generic term for more than 100 different diseases, including malignant tumours of different sites. Cancer is becoming an increasingly important part in the burden of disease in all parts of the world. The disease accounts for 12.6% (7.1 million) of global deaths annually. The number of new cases annually is estimated to rise from 10 million to 15 million by 2020 (WHO, 2002).

Cancer arises principally as a consequence of individual exposure to carcinogenic agents in what individuals eat, drink and inhale, or are exposed in their environment. Personal habits rather than genetic factors play the major roles in the development of most cancers. Tobacco use is the single largest causative factor, and also an unhealthy diet, lack of physical activity and the consequent overweight and obesity are important reasons for the high and increasing prevalence of cancer (WHO, 2003).

Strong evidence indicates that physical inactivity is associated with a 30 to 40% higher risk of colon cancer. Somewhat less consistent but sufficient evidence indicates that physical inactivity increases the risk of breast cancer in pre- and postmenopausal women by 20 – 30% (Friedenreich, 2001; Lee, Rexrode, Cook, Hennekens, & Burin, 2001; Thune & Furberg, 2001; Vainio & Bianchini, 2002; Dorn, Vena, Brasure, Freudenheim, & Graham, 2003; McTiernan, Kooperberg, White, Wilcox, Coates, Adams-Cambell et al., 2003, Rintala et al., 2002, 2003). Limited evidence supports the notion that physical inactivity is associated with increased risk of endometrial and prostate cancer (Vainio & Bianchini, 2002; Dhillon & Holt, 2003; Furberg & Thune, 2003). The observations on the relationships between physical activity and other cancers have been inconsistent. Low levels of aerobic fitness, at least partly attributable to lack of regular physical activity, seem to be associated with

increased cancer mortality (Lee & Blair, 2002b; Evenson, Stevens, Cai, Thomas R., & Thomas O., 2003; Sawada, Muto, Tanaka, Lee, Paffenbarger, Shindo, & Blair, 2003). Several plausible mechanisms such as lengthy intestinal transit time (colon cancer), worse immune functions, and unfavourable effects on body weight as well as on reproductive and metabolic hormones and their effects have been proposed to explain the increased risk in sedentary as compared with physically active subjects but none of the mechanisms have been proven (Bianchini, Kaaks, & Vainio, 2002; Friedenreich & Orenstein, 2002).

All-cause mortality. The most serious effects of physical inactivity on diseases are summed up in the data of all-cause mortality. Several tens of scientific studies have found that physical inactivity increases the risk of all-cause mortality, the major component being cardiovascular diseases (Lee & Skerrett, 2001). This association is evident in men and women, and in younger and older persons. Physically inactive persons have a 20 to 30% increased risk of all-cause mortality as compared with those who adhere minimally to the current physical activity guidelines (at least 30 minutes of at least moderate intensity physical activity on most days of the week). The difference in risk increases linearly with the increasing volume of physical activity in the active persons, and the sedentary persons experience up to double the risk of the very active subjects. When the risk of persons with low and high cardiorespiratory fitness is compared, the low-fit persons have up to five times greater risk as compared with the high-fit subjects (Lee & Skerrett, 2001). The increased risk of all-cause mortality associated with physical inactivity is seen also in persons with chronic diseases. It is not known if physical inactivity reflects an independent mortality risk in these persons or if it is a proxy for other factors that increase mortality risk (Martinson, O'Connor, & Pronk, 2001).

The World Health Report 2002 gives global estimates of the burden of physical inactivity in terms of e.g. mortality. The estimates are based on deaths caused by coronary heart disease, stroke, breast cancer, colon cancer, and type 2 diabetes. For various reasons the deaths due to other causes related to physical inactivity are not included. These exclusions as well as the definitions of physical inactivity and an insufficient level of physical activity in the report have led to underestimation of the deaths caused by physical inactivity.

The World Health Report 2002 estimates that physical inactivity causes 1.9 million deaths annually in the world. In developed or industrialised countries the proportion of deaths attributable to physical inactivity is 5 – 10%. The rank order of physical inactivity among the risk factors is 7th in developed countries. In Australia physical inactivity is estimated to be attributable to 8.7% of deaths among men and 11.7% of deaths among women (Mathers, Vos, Stevenson, & Begg, 1999, 2001). In Denmark it is estimated that if the currently inactive persons in the population would become physically active (at least 4 hours per week) the mortality rate for coronary heart disease would decrease by 3% for men and 6% for women in 15 years (Bronnum-Hansen, 2002).

Physical activity as the causal remedy of the health-damaging effects of physical inactivity

When physical activity is recommended or even marketed as a means to improve health, the claims of its effectiveness have to be strongly substantiated by scientific evidence. Assessment of the surety and level of the health benefits of physical activity is a demanding and responsible task. The requirements for the correctness of the assessment increase with increasing specificity of the effects of physical activity, increasing risks and costs involved in practising the necessary physical activity, and with poorer and more complicated health status of the persons who would use physical activity for the specified purpose. Thus, recommendation of being regularly physically active in ordinary modes is completely acceptable for most people as a measure for maintaining and improving the general health and functional capacity, and for decreasing the risk of common chronic diseases, because it is just a matter of an inherent part of the eternal lifestyle pertaining to normal human life and living. However, recommendation of specialised, may be a costly exercise program for a patient with e.g. cardiac insufficiency requires solid evidence of the effectiveness and safety of the applied measure. Thus, the spectrum of health-enhancing physical activity ranges from general, self-conducted activity for general health to highly specialised, professionally planned and supervised exercise programs for specified medical purposes.

Physical activity can be practised as part of daily chores e.g. in maintenance and repair work of the house, as walking or cycling as a means of transport, as part of recreation and hobbies,

e.g. bird watching, as exercise for fitness, health or pleasure, as sports, or even as part of work. Thus, the spectrum of physical activity is wide and all its domains have to be considered in examining its health-enhancing potential and in promoting it for health. However, all types of physical activities and the ways in which they are practised do not have similar or equally large effects on health. In order to give correct advice and recommendations on health-enhancing physical activity we have to know the key characteristics of the effective dose of activity for various purposes as well as to what degree the characteristics of the effective dose are met in the practice of physical activity at the various domains. Thus, if we want to recommend e.g. domestic chores or walking as transport for the prevention of coronary heart disease, we have to know if and to what degree these activities meet the criteria of effective activity for this purpose.

The effectiveness of physical activity in producing intermediate health outcomes such as health-related or health-enhancing changes in organ structures, functions, and regulations should be assessed mainly on the basis of the results of randomised controlled trials. However, there are no studies of this kind on the preventive effects of physical activity on chronic diseases such as coronary heart disease and cancer as outcomes, and it is unlikely that many of those kind of studies will ever be conducted. The same is true to a large extent regarding the evidence of the effectiveness of physical activity in rehabilitation and secondary prevention of many diseases. The lack of the strongest evidence does not mean, however, that it would be unjustified to claim physical activity to be effective or that stronger evidence should be waited for, if the evidence from reliable research is already strong and the characteristics of effective physical activity are known to a sufficient degree for practical purposes as is the case of e.g. coronary heart disease.

It seems that many if not most of the effects of physical activity the level of activity and that meets the "thresholds" for stimulatory effects cannot be defined in absolute terms but rather in relation to the state of the structure or function in question. This relativity may mean also, that the same physical activity in absolute terms produces clearer health-enhancing effects in the very sedentary as compared with more active persons and populations, and that for very sedentary persons and populations even a slight increase of physical activity may be beneficial. Consequently, some increase in e.g. habitual walking might show definite health benefits in populations that spend much time in sitting in a car or watching TV, but the same amount of increase of walking in populations used to walking tens of minutes or even hours daily would not show any change in health outcomes.

The "threshold" levels for various health-enhancing effects of physical activity are continuously sought. It is likely that many of these "thresholds" are not abrupt changes in the amount, intensity or frequency of physical activity causing off – on-effects but rather subtle changes on a continuous scale. Epidemiological studies suggest these levels to be somewhat lower than what is found in clinical trials. This seeming discrepancy may be due at least partly to the shorter exposure times and use of intermediate or proxy measures of the health outcomes in the clinical trials. In epidemiological studies the gradually developing, even modest effects of physical activity have time to influence separately and combined with the disease processes for periods lasting years or tens of years. In any case, accumulating evidence indicates that the probably more or less sliding "threshold" level of physical activity e.g. for metabolic and consequently cardiovascular health-enhancing effects is around a 30 to 40% increase above the basal level or this proportion of the maximal aerobic capacity.

Muscle mass, strength and power, sarcopenia. Increased physical activity can increase the mass, strength, endurance, and power of the muscle. In general muscle force is increased when the static or dynamic contractions exceed 50 – 60% of the maximal strength expressed either as maximal voluntary contraction (MVC) in isometric or static exercise or the performance of one maximal bout of dynamic contraction (1 RM = repetition of maximum, i.e. maximum amount of weight that can be lifted with one contraction). In static training the highest gain in muscle strength can be gained by using maximal force rather than by increasing the number of contractions. In dynamic training the most pronounced effects in strength gain are evident with resistance training containing six or fewer repetitions in one training series prior to fatigue. Muscle mass is increased effectively by repeating moderate loads (6 – 12 RM), while training with heavy loads (1 – 8 RM) causes various neural adaptations that lead to an increased rate of force development.

The morphological adaptations include an increase in the cross-sectional area of especially the type II (fast contracting) muscle fibers due to increased protein synthesis as well as changes in the internal architecture of the muscle. The cross-sectional area of type I fibers can increase by about 50% and that of the type II fibers by 100%. Hypertrophy of the muscle fibers begins to be measurable in 4 – 6 weeks (Kjaer, Kalimo, & Saltin, 2003). The neural adaptation mechanisms include several changes both within the muscle and in its neural control (Aagaard & Thorstensson, 2003). These changes occur especially during the first 4 – 6 weeks of training, and they are seen also in the contralateral, non-trained extremity.

Muscle training with low loads but a high number of repetitions results in no marked strength increase, whereas muscle endurance is improved substantially. The underlying changes include increased capillary density, the number of mitochondria and the amount of oxidative and glycolytic enzymes.

The effects on the morphology and performance of muscle training are most needed in elderly people with various degrees of sarcopenia and its consequences. Well-conducted clinical trials show convincingly that muscle training of elderly and even frail old individuals (Fiatarone, Marks, Ryan, Meredith, Lipsitz, & Evans, 1990; Fiatarone, O'Neill, Ryan et al., 1994) is both possible and effective as demonstrated by e.g. an increase of about 10% in muscle size and over 100% increase in muscle strength. Very importantly, the effects on muscle strength were reflected also in improved functional performance, e.g. in the gait speed, climbing stairs, carrying packages, and balance.

Good muscular performance includes low resistance to movements, good **mobility or flexibility**. One important factor causing resistance to movements or stiffness is the amount and quality of connective tissue and its main macromolecule, collagen, in the muscles, tendons and joint capsules. Stiffness or inversely flexibility varies greatly between individuals. It depends largely on two factors, the viscoelastic properties of the tissues and tolerance to tensile load. Decreasing viscoelasticity and consequently increasing stiffness are well-known phenomenon in ageing. They are largely caused by increasing amounts of collagen and its qualitative changes. The same changes also make the connective tissue more brittle and vulnerable to mechanical stress. Collagen responds unfavourably to inactivity and favourably to activity regarding its functional properties (Harridge & Suominen 2003; Magnusson, Takala, Abramowitch, Loh, & Woo SL-Y, 2003). Stretching exercises cause, however, only temporary improvement in the passive viscoelastic properties of the muscle-tendon unit lasting about one hour, but more lasting effects are due to increased tolerance to tensile loads (Magnusson et al., 2003). The mechanism for this altered stretch tolerance is not known. From a clinical point it is important to notice that although flexibility exercises do not cause lasting changes in the passive properties of the muscle-tendon unit, they lead to an increase in the joint range of motion.

The effects of physical activity on muscle and adjacent tissues have several health-enhancing consequences especially in persons with poor muscular fitness and sarcopenia. Increased muscle strength allows more rapid movements and more force in rapid movements. Strong muscles protect the joints from instability and injuries. Sufficient muscle strength is required to maintain bone mass and strength, and muscle tissue and fast muscular contraction decrease the impact in falling. Gait velocity is increased, and stair climbing and other daily activities are easier or possible to perform. Increased muscle mass increases the aerobic power and thus endurance capacity and possibilities for activities requiring this ability. Reasonable endurance capacity is valuable also for sufficient energy expenditure in order to improve the appetite for a sufficient nutrient intake as well as to support weight management. In several studies on muscle training in the elderly also overall physical activity has increased. Many of the effects stated above contribute to a better quality of life (Evans, 2002). Physical activities that maintain and increase muscle mass and strength are a key component in the recommendations for health-enhancing physical activity especially for elderly people (ACSM, 1998a, b).

Bone mass, osteoporosis and risk of fractures. Physical activity increases bone mass and consequently bone firmness in men and women of all ages. The stimulus for increased bone mass is a rapid transient change of the length of the bone, strain, caused in physical activity either by impacts that lead to compression or dynamic muscle pull that cause torsion. Thus, physical activities that cause substantial impacts on bones such as jumping or that cause high compressive or torsional loads such as

weight lifting are effective modes to influence bone. Compressive load increases especially bone mass and torsional load influences bone geometry or mass distribution increasing the bone firmness without large changes in the mass (Heinonen, Sievänen, Kannus, Oja, & Vuori, 2002). Fast walking may cause sufficient impacts especially in subjects with weak bones to induce an increase of bone mass (Hatori, Hasegawa, Adachi et al., 1993; Iwamoto, Takeda, Otani, & Yabe, 1998; Iwamoto, Takeda, & Ichimura, 2001), but in general there is little evidence supporting the effectiveness of walking and other low-impact activities to increase bone mass (Vuori, 2001a). The effects of physical load are always seen only at the exact site of the increased load. The characteristics of effective stimulus for bone mass and firmness mean that the activities for this purpose need to be veried specific regarding the site of the desired effect as well as the type of activity (Vuori & Heinonen, 2000). The margin between highly effective and risky activities tends to be narrow especially in elderly subjects not accustomed to vigorous exercises.

The effect of physical activity on bone is greatest at the time of rapid growth as mentioned above. The bone mass can be over 30% higher in the most loaded parts of the bones of the playing (dominant) as compared to the non-playing arm of racket sports players who have started systematic training in childhood. The difference is much less in those players of comparable standard who have started the training after puberty (Kannus et al. 1995; Haapasalo et al., 1998). Importantly, the extra bone mineral gained by intensive load is in large part due to increased bone dimensions, total cross-sectional area and cortical wall thickness (Haapasalo, Sievänen, Kannus, Heinonen, Oja, & Vuori, 1996; Morris, Naughton, Gibbs, Carlson, & Wark, 1997; Heinonen, Sievänen, Kyröläinen, Perttunen, & Kannus, 2001) that are important for bone breaking strength. Thus, studies on high-level athletes have shown that bone is highly adaptable to physical load during youth. However, controlled exercise trials of about one year duration on school aged children have shown much smaller effects, a mean 2 - 5% net increase in lumbar spine and femoral neck bone mass in the exercising groups (Heinonen, Sievänen, Kannus, Oja, Pasanen, & Vuori, 2000; Fuchs, Bauer, & Snow, 2001; Mackelvie, McKay, Khan, & Crocker, 2001). The smaller effect in these trials as compared with the findings of observational studies can be explained e.g. by a shorter exposure time to a much weaker stimulus in the controlled trials. On the other hand, the exercise programs consisting largely of jumping exercises were found to be safe and feasible. Some evidences suggest that the effects of intensive physical activity in childhood and adolescence on bone can be to a large degree maintained for at least several years with much less and less intensive activity than that which was done in gaining the high bone mass (Kontulainen, Heinonen, Kannus, Pasanen, Sievänen, & Vuori, 2001; Kontulainen, Kannus, Haapasalo, Sievänen, Heinonen, Oja, & Vuori, 2004).

Physical activity influences bone favourably also during the adult years although the effects of safe and feasible exercise programs have been found to be rather modest. The analyses of a large number of controlled trials reveal that physical activity can maintain or even slightly increase bone mass in premenopausal and substantially decrease the loss of or maintain or even slightly increase (~ 1%/year) bone mass in the lumbar spine and femoral neck in perimenopausal and postmenopausal women. These findings are seen quite constantly in studies that have used intensive high-impact or resistance exercises and that have lasted for at least one year (Vuori, 2001a; Cheng, Sipilä, Taaffe, Puolakka, & Suominen, 2002; Kemmler et al. 2003). The response seems to be of the same magnitude in both women and men (Welsh & Rutherford, 1996; Karlsson, 2002), and positive responses have been seen also in frail and osteoporotic subjects (Iwamoto, Takeda, Otani, & Yabe 1998; Iwamoto, Takeda, & Ichimura, 2001; Kohrt, Yarasheki, & Hollszy, 1998). Although the effects of physical activity on adult bone seem to be small, the average 1% per year difference in bone mass change in favour of physically active subjects is potentially important regarding the fracture risk, as small differences in bone mass translate to a substantial difference in fracture risk (Cummings, Black, Nevitt et al., 1993). Furthermore, evidence from cross-sectional studies suggests that lifetime physical activity may result in larger and mechanically more competent bones at the loaded sites, and these effects are not readily observable in measuring bone mass by conventional techniques (Uusi-Rasi et al., 1998, 2002).

Physical activity can influence favourably also several intrinsic risk factors for falls (American Geriatrics Society et al., 2001) including muscle strength (6 to 174% im-

provement in different studies), range of motion (0.5 to 18% improvement), balance (7 to 53% change), gait (12 to 48% improvement), and reaction time (0 to 4% improvement) (Myers, Young, & Langlois, 1996). Reviews of clinical trials indicate that exercise programs to improve gait, balance and muscle decreased falls by 19 – 46% and injuries due to falls by 28 – 88% in elderly men and women living at home as compared with control subjects. The benefits were greatest in subjects over 80 years, and the programs were cost-effective (Gillespie L.D., Gillespie W.J., Robertson, Lamb, & Rowe, 2002; Gregg, Pereira, & Caspersen, 2002; Robertson, Cambell, & Gardner, 2002; Tinetti, 2003). A recent large follow-up study in postmenopausal women found that the risk of hip fracture was lowered by 6% for each increased hour walked in a week at an average pace. The women whose physical activity corresponded to at least 60 – 70 minutes of walking daily had 55% lower risk of hip fracture compared with their sedentary counterparts. Among women who did no other exercise, walking for at least 4 h/wk was associated with a 41% lower risk of hip fracture compared with walking less than 1 h/wk (Feskanich, Willett, & Colditz, 2002).

In conclusion, current evidence shows convincingly that physical activity is an important factor in prevention of osteoporosis and related fractures by increasing or maintaining bone mass and strength and by decreasing the risk of falls through the favourable effects on the several risk factors for falls. Various factors contributing to the final preventive effect of physical activity are most effectively influenced in the different stages of life from early childhood to old age, and by greatly different activities. This means that prevention of fragility fractures by physical activity calls for a physically active lifestyle throughout life.

Joints and arthritis. Physical activity can be beneficial for joints through its effects on the joint cartilage and on the adjacent structures, especially muscles. Weight-bearing physical activities cause compression of the cartilage and change of pressure in the joint space thereby facilitating the nutrition of non-vascular cartilage. Animal studies show that moderate physical activity causes beneficial structural and functional changes in joints (Arokoski, Jurvelin, Vaatainen, & Helminen, 2000). Corresponding observations in humans are lacking, but Helminen and co-workers (2000) have hypothesised that regular joint load by physical activity in youth may contribute to the prevention of osteoarthritis later in life. Furthermore, indirectly regular physical activity may decrease the risk of osteoarthritis by preventing being overweight and obesity and by protecting the joints from injuries and malalignments by maintaining sufficient muscle strength for the stabilisation of the joints.

The effects of physical activity are important also for persons with already developed osteoarthritis in order to prevent a deterioration of the joint status. Indeed, regular exercises including stretching, range of motion activities, resistance training and aerobic conditioning have been found beneficial for patients with especially knee osteoarthritis by decreasing pain, stiffness and functional limitations. Physical activity may break the vicious circle often found in these patients that may include deterioration of aerobic and muscular fitness, flexibility, proprioception, and balance as well as weight gain, development of cardiovascular risk factors, depressive mood, lack of self-confidence and initiative, decreasing capacity for activities of daily living, increasing dependency, and development of comorbidities (Ettinger, 1998; Brandt, 1998; Walker-Bone, Javaid, Arden, & Cooper, 2000; Resnick, 2001). Systematic reviews of controlled exercise trials have found substantial evidence for these benefits (Ettinger, 1998; Van Baar, Assendelft, Dekker, Oostendorp, & Bijlsma, 1999; Felson et al., 2000; Vuori, 2001a). No studies indicate that appropriate exercise exacerbates the symptoms or accelerates cartilage degeneration in patients with ostoartrhritis, and in general exercise programs have been found safe and well tolerated by these patients (Sharkey, Williams, & Guerin, 2000). Currently exercise is recommended as an essential part of comprehensive treatment and secondary prevention of osteoarthritis (American College of Rheumatology, 2000).

Much of what has been stated above applies also to rheumatoid arthritis in its non-acute, stabile phase (Van den Ende et al., 1998; Hakkinen, Sokka, Kotaniemi, & Hannonen, 2001; Sokka, Lietsalmi, Kautiainen, & Hannonen, 2003), and exercise has reached an approved status as part of the management of rheumatoid arthritis.

Physical activity can be also detrimental to joints, if it causes repeated high impacts on or injuries of the joint, or if the loading of the joint takes place in unfavourable positions such as in kneeling or during torsion. However, even large amounts of moderate physical activity

such as walking or jogging does not lead to osteoarthritis in healthy, normal weight subjects whose joints have normal structural and functional characteristics (Vuori, 2001a).

Low back pain. Evidence from controlled studies indicates that regular non-injurious physical activity may prevent low back pain, and currently it is the only scientifically tested modality for this purpose (Nachemson & Jonsson, 2000; Van Tulder et al., 2000). Exercise programs have been found beneficial also in the management of chronic although not of acute low back pain. Unfortunately the characteristics of effective physical activity for the prevention and management of low back pain and their mechanisms of action are not known with certainty (Vuori, 2001a). This weakens the possibilities for rational and effective use of physical activity for the mentioned purposes. Furthermore, the beneficial effects of exercise may be partly due to psychological, social and other circumstantial and environmental factors and not based on biological mechanisms.

Neck pain. Pain and stiffness in the neck region are experienced by up to 50% of the population of the industrialised countries (Nachemson & Jonsson, 2000), and it is especially common in women. The symptoms become chronic in 5 to 7% of the working aged populations (Coté, Cassidy, & Carroll, 2000). The origin and pathophysiological mechanisms of chronic neck pain remain obscure. Systematic analysis of earlier studies (Nachemson & Jonsson, 2000) and some (Randlov, Ostergaard, Manniche, Kryger, Jordan, Heegaard, & Holm, 1998; Taimela et al., 2000; Ylinen, Takala, Nykänen, Häkkinen, Mälkiä, Pohjolainen et al., 2003) although not all (Viljanen, Malmivaara, Uitti, Rinne, Palmroos, & Laippala et al., 2003) recent randomised trials provide evidence that physical activity to exercise the neck muscles is effective in alleviating pain and self-experienced disability caused by chronic neck pain. There are no reports suggesting a preventive effect of physical activity on this disorder.

Overweight and obesity. Physical activity has an important role in preventing obesity by increasing energy expenditure and thus contributing to the maintenance of energy balance when faced with an abundance of food as discussed earlier in this article. The amount of physical activity needed for the prevention of becoming overweight and obese seems to correspond to 45 – 60 minutes of moderate intensity activity such as brisk walking in a large part of the populations of the industrialised countries (Saris, Blair, Van Baak, Eaton, Davies, Di Pietrol et al., 2003). In weight reduction physical activity alone leads to only modest (some kilograms) weight loss, and exercise combined with low energy diet does not increase the weight loss substantially. Physical activity after intentional weight reduction in previously obese subjects is not very successful in preventing weight regain (Fogelholm & Kukkonen-Harjula, 2000; Vainio & Bianchini, 2002). One reason for these findings is that the amount of physical activity needed to induce sufficient negative energy balance for substantial fat loss is large, approximately 6300 – 8400 kJ/week (1500 – 2000 kcal/week corresponding to 60 – 90 minutes brisk walking daily) in addition to energy consumed in daily living (Saris et al., 2003). This requirement of physical activity often exceeds the motivation and possibilities of overweight and obese persons.

The role of physical activity in relation to being overweight and obesity should not be judged only on the basis of the effect of activity on body weight, because physical activity can bring important benefits to overweight and obese people also without any marked weight loss. Endurance training can improve the metabolic risk factors of cardiovascular diseases as well as fitness, and resistance training spares muscle mass in conjunction with dieting (Vainio & Bianchini, 2002). The evidence from well-controlled, short-term trials provide strong evidence that increasing physical activity is positively related to reductions in total adiposity in a dose-response manner as well as to reductions in abdominal and visceral fat (Ross & Janssen, 2001). Physical activity can also have beneficial effects on several comorbidities of obesity (Grundy, Blackburn, Higgins, Lauer, Perri, & Ryan, 1999). In general, physical activity has the potential to bring the same health benefits to overweight and obese persons as to their normal-weight counterparts. Furthermore, overweight and obese people are in greater need of these benefits because of the higher risk, incidence and prevalence of conditions of ill health among them as compared with normal-weight subjects. Epidemiological studies have provided that part of the increased risk of morbidity and mortality associated with excess body mass is not caused by the obesity itself but by physical inactivity underlying commonly the development and maintenance of being overweight and obesity (Blair & Brodney, 1999).

Type 2 diabetes. Increasing physical activity decreases the risk of Type 2 diabetes, and also this effect seems to be related to the dose of activity (Kelley & Goodpaster, 2001). The value of physical activity in the prevention of diabetes has been shown convincingly in several large scale non-randomised (Erikson & Lindgärde, 1991; Pan, Li, Hu et al., 1997) and randomised (Tuomilehto, Lindström, Eriksson, Valle, Hämäläinen, Ilanne-Parikka et. al., 2001; Diabetes Prevention Program Research Group, 2002) controlled trials. The risk of developing diabetes has been up to nearly 60% lower in the intervention as compared to the control groups. A part of this effect has been due to simultaneous dietary changes. The preventive effect of physical activity is greatest in subjects with a high risk of diabetes. Physical activity is beneficial also in subjects who already have diabetes e.g. by influencing favourably the risk factors of other chronic diseases, by decreasing the need of drug treatment, and by improving fitness and mood (Wallberg-Henriksson, Rincon, & Zierath, 1998; Hamdy, Goodyear, & Horton, 2001; Maiorama, O'Driscoll, Cheetham, Dembo, Stanton, Goodman, Taylor, & Green, 2001; Stewart, 2002) and by decreasing morbidity (Hu et al., 2001b) and mortality (Wei et al., 2000). Both moderate to vigorous aerobic activities as well as resistance training are effective, and it is recommendable to do them in combination (Eriksson, 1999). Exercising shows some beneficial effects on insulin resistance syndrome already in children (Ferguson, Gutin, Le, Karp, Litaker, Humphries et al., 1999).

Hypertension. Increased physical activity has substantial beneficial effects related to blood pressure and its consequences. A single bout of physical activity decreases the blood pressure level for up to about 20 hours (ACSM, 2004). Exercise lowers blood pressure, but the effect shows a wide variation in different studies, and meta-analyses and systematic reviews on these studies give slightly different results (Fagard, 1999; Kelley, 1999; Hagberg, Park, & Brown, 2000; Kelley & Kelley, 2000; Whelton, Chin, Xin, & He, 2002a). They indicate constantly, that both aerobic and resistance training at moderate or vigorous intensity lower resting systolic and diastolic blood pressure on average by 2- 3 mm Hg in normotensive and by 6 – 7 mmHg in hypertensive subjects (Fagard, 1999). A positive response to exercise training is seen in about 75% of the subjects (Hagberg, Park & Brown, 2000), and it is seen in men and women of various ages, people of normal weight and obese ones as well as in normotensive and hypertensive subjects, and it can be achieved by exercise programs that vary considerably in their content (intensity, frequency and duration of the activity) (Fagard, 2001). The effect of exercise takes place without any change in body weight but it is enhanced by weight loss (Blumenthal, Sherwood, Gullette, Babyak, Waugh, Georgiades, et al., 2000; Steffen, Sherwood, Gullette, Georgiades, Hinderliter, & Blumenthal, 2001).

Tha possible mechanisms of the effect of exercise include attenuation of sympathetic activity, increased insulin sensitivity and a decreased level of circulating insulin, decreased peripheral resistance, increased baroreflex sensitivity, changes in the rennin-angiotensin-aldosterone system, and a reduction of body fat (ACSM, 2004). Examples of possible indirect mechanisms include improved relaxation and decreased tension and anxiety. Additional important benefits of physical activity for hypertensive subjects are improvements in other risk factors for cardiovascular and metabolic diseases, because these changes potentate the risk reduction caused by decreased blood pressure. Furthermore, physical activity may lead to regression of pathological enlargement of the left ventricle of the heart and attenuate the blood pressure response to physical exertion (Hagberg, Park, & Brown, 2000; Kokkinos, Narayan, & Papademetriou, 2001; Ehsani, 2001; Stewart, 2002) as well as to mental stress (Georgiades, Sherwood, Gullette, Babyak, Hinderliter, Waugh et al., 2000). Hereditary factors seem to influence the blood pressure response to exercise and training (Rankinen B., Rankinen T., & Bouchard, 2002; Rice, An, Gagnon, Leon, Skinner, Wilmore, Bouchard, & Rao, 2002).

On the whole, physical activity may decrease the risk of acute cardiovascular complications and development of cardiovascular diseases in subjects with elevated blood pressure (Hagberg, Park, & Brown, 2000; Church, Kampert, Gibbons, Barlow, & Blair, 2001). Physical activity is currently included in the recommendation of primary prevention of hypertension (Whelton, He, Appel, Cutler, Havas, Kotchen et al., 2002b; ACSM, 2004).

Metabolic syndrome. Increased physical activity in the form of aerobic exercise training is effective in reducing the various components of metabolic syndrome in obese children (Ferguson et al., 1999) as well as in adults with this syndrome to the degree that a

substantial number of the subjects participating in an exercise program did not any more meet the criteria of the syndrome at the conclusion of the program (Katzmarzyk, Leon, Wilmore, Skinner, Rao, Rankinen, & Bouchard, 2003).

Coronary heart disease. The findings from epidemiological studies referred to previously in this review, as well as several plausible biological mechanisms that can explain the decreased risk of developing coronary heart disease and its complications, and the beneficial effects of increased physical activity on these mechanisms (Table 2) (Tegos et al., 2001; Giannuzzi, Mezzani, Saner,Björnstad, Fioretti, Mendes et al., 2003), indicate strong-ly even in the absence of intervention trials that coronary heart disease risk can be decreased substantially in men and women of all ages by increasing physical activity. The characteristics of effective physical activity are rather well known, and there is a dose – the response relationship between the decrease of risk and the amount of physical activity (Kohl, 2001). The current recommendation of at least 30 minutes of moderately intensive aerobic physical activity on most days of the week has been developed largely on the basis of findings on the effectiveness of physical activity on coronary heart disease prevention, and is continuously the basic recommendation for this purpose. However, a larger total volume and probably also a higher intensity of physical activity increase its protective effect. Physical activity is included in the recommendations for prevention of coronary heart disease of major scientific and professional organisations (e.g. American Heart Association; Fletcher et al. 1995; Thompson et al. 2003; European Society of Cardiology; Giannuzzi, Balady, Froelicher, Hartley, Haskell, & Pollock, 2003; WHO, 2003).

Physical activity is also an effective part of *cardiac rehabilitation* programs in reducing the total cardiac mortality by 31% and coronary artery mortality by 35% (Jolliffe, Reeves, Taylor et al., 2003), and by improving the functional capacity and quality of life of the patients (Gibbons, Abrams, Chatterjee et al., 2003). The mechanisms responsible for the beneficial effects of physical activity in secondary prevention and rehabilitation of patients with coronary heart disease are to a large extent the same as those in the primary prevention (Ades, 2001; Giannuzzi et al., 2003).

Chronic cardiac failure (insufficiency) is a consequence of many heart diseases but most often of coronary heart disease. Until recently chronic cardiac failure was regarded as a warning symptom precluding any strenuous physical activity. Several exercise training studies have shown, however, that patients with mild to moderate (Belardinelli, Georgiou, Cianci, & Purcaro, 1999) and even severe (Erbs, Linke, Gielen, Fiehn, Walther, Yu et al., 2003) forms of this condition tolerate individually adjusted physical activity well and benefit from it in several ways, e.g. by having improved cardiac function, fewer symptoms, and increased functional capacity and muscle strength. On the basis of the evidence of the benefits physical activity is recommended as a part of the comprehensive care of patients with cardiac failure (Pinã, Apstein, Balady, Belardinelli, Chaitman, Duscha et al., 2003).

Table 2. Mechanisms by which increased physical activity may contribute to prevention of coronary heart disease and its sequalae (compiled from several sources)

Increased plasma HD-lipoprotein
Decreased plasmaLD-lipoprotein and total cholesterol
Decreased serum triglycerides
Decreased blood pressure
Improved insulin sensitivity, decreased insulin concentration and improved glycemic control
Decreased sympathetic and increased parasympathetic drive
Decreased heart rate at rest and during effort
Increased heart rate variability and baroreflex sensitivity
Improved endothelial function
Improved contractility of the heart muscle
Improved collateral circulation in ischaemic heart
Improved electrical stability of ischemic heart
Decreased tendency to blood clotting (transiently after a bout of activity)?
Increased fibrinolysis (transiently after a bout of activity)?
Improved weight management
Improved aerobic fitness
Less smoking
Better coping with stress
Attenuation of inflammatory response?

Cerebro-vascular disease (stroke). Increased physical activity has not been directly shown by exercise intervention trials to decrease the risk of stroke. However, the quite consistent findings of a number of prospective studies, showing decreasing risk with increasing levels of physical activity, the plausible biological mechanisms that can explain the effects of physical activity, and the favourable effects of physical activity in well-controlled trials on the risk factors of stroke warrant the notion that physical activity is an effective measure for

stroke prevention (Kohl, 2001; Lee, Folsom, & Blair, 2003; Wendel-Vos, Schuit, Feskens, Boshuizen, Verschuren, Saris, & Kromhout, 2004). Even a moderate dose of physical activity in terms of the amount and intensity, e.g. brisk walking half an hour on most days of the week, has been found to decrease the risk of stroke (Hu et al., 2000). In part of the studies this effect has increased with a greater amount and/or a higher intensity of physical activity, and currently the dose-response relation has been shown by meta-analysis (Oguma & Shinoda-Tagawa 2004). Physical activity is included in the recommendations for prevention and rehabilitation of stroke (Gorelick et al., 1999; Goldstein et al., 2001).

Peripheral arterial disease (Claudicatio intermittens). Physical activity, particularly such as supervised walking exercising, is very effective in the treatment and secondary prevention of this condition improving the painless walking distance on average by 150% (Leng, Fowler, & Ernst, 2000; Stewart et al., 2002), more than other modes of conservative treatments. This effect can be explained by several mechanisms including improvements in endothelial vasodilator function, skeletal muscle metabolism, blood viscosity, inflammatory response, and biomechanics of walking. The exercise-induced increase in walking distance translates also to improvement in routine daily activities. Furthermore, exercising is likely to influence positively several risk factors of atherosclerotic diseases.

Cancer. Currently it is not known how much the risk of certain cancers could be prevented by physical activity and what would be the appropriate "dose" of physical activity. This uncertainty is greater than in the case of the other chronic diseases discussed above, because the mechanisms of the preventive effects of physical activity and consequently the factors to be targeted by physical activity are not known with certainty. The "most educated guess" is to recommend regular physical activity several times a week at moderate intensity and for at least half an hour per session, because this "dose" has been found appropriate for some important effects related to cancer prevention such as weight management and stimulation of immune functions (Woods, Davis, Smith, & Nieman, 1999; Mackinnon, 2000) as well as to many other health benefits of physical activity. This "dose" corresponds to the recommendation of American Cancer Society (Byers, Nestle, McTiernan, Doyle, Currie-Williams, Gansler, & Thun, 2002). Physical activity has been found beneficial also in the management of cancer patients (Fairey, Courneya, Field, & Mackey, 2002).

Cognitive impairment with ageing. Decline of cognitive function and especially dementia e.g. in the form of Alzheimer disease are feared phenomena related to ageing. About 7 - 10% of the population aged 65 and up to 50% of persons over the age of 85 have Alzheimer disease (McDowell, 2001; Ball & Birge, 2002). Because of the rapidly increasing number of older people, much attention has been directed to cognitive impairment including its prevention.

Brain ageing and the expression of dementia can be conceptualised as an imbalance between neuronal injury and repair. The injury can be caused by a great number of factors, e.g. ischaemia due to compromised blood flow as a result of atherosclerosis of the brain vessels, and by genetic and environmental factors. This balance can be affected by modifying the age-related factors, e.g. the risk factors of atherosclerosis.

A number of cross-sectional and follow-up studies have found positive or no associations between physical activity and cognitive function (Anstey & Christensen, 2000). Several recent cross-sectional (Elwood, Gallacher, Hopkinson, Pickering, Rabbitt, Stollery et al., 1999; Stewart, Richards, Brayne, & Mann, 2001) and longitudinal (Ho, Woo, Sham, Chan, & Yu, 2001; Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001; Yaffe, Barnes, Nevitt, Lui, & Covinsky et al., 2001; Lindsay, Laurin, Verreault, Hébert, Helliwell, Hill, & McDowell, 2002; Abbott, White, Ross, Masaki, Curb, & Petrovitch, 2004; Weuve et al., 2004) studies with sufficient power to show significant associations have provided evidence suggesting that physical activity could have a protective effect against the development of cognitive impairment and dementia with ageing, and several recent reviews have included physical activity as one of the potentially effective preventive means (McDowell, 2001; Ball & Birge, 2002; Fillit, Butler, O′Connell, Albert, Birren, Cotman, et al., 2002). Physical activity, especially when done in versatile modes requiring and developing motor skills, may be one form of "brain gymnastics" in the same way as intellectually challenging tasks. Exercise may be beneficial also in the management of patients with Alzheimer disease (Teri, Gibbons, McCurry, Logdon, Buchner, Barlow et al., 2003).

Concluding statement

Current scientific evidence indicates convincingly, that physical inactivity is a serious hazard to health, functional capacity and well-being that affects to various degrees the major part of the population in most countries of the world. These adverse effects are increased by inadequate diet and other factors frequently connected to the prevalent lifestyles in industrialised countries and more and more also in countries in transition and in developing countries. Fortunately the causal antidote to physical inactivity, i.e. regular moderate physical activity, is definitively known. Unfortunately, however, there are a number of perceived and objective physical, physiological, psychological, social, cultural, and economic obstacles for the adoption of regular physical activity in all populations. Although physical activity belongs largely to the private domain of individuals, society is responsible for providing sufficient information of the importance of regular physical activity and opportunities to be physically active in feasible and safe ways.

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TJELESNA NEAKTIVNOST JE UZROK, A TJELESNA AKTIVNOST LIJEK ZA GLAVNE JAVNOZDRAVSTVENE PROBLEME

Sažetak

Uvod

Čvrsti znanstveni dokazi pokazuju da su mnoge bolesti ili prekursori bolesti češći u osoba koje se rijetko ili uopće ne bave tjelesnom aktivnošću nego kod redovito fizički aktivnih osoba. Broj bolesti ili stanja koje potiče tjelesna neaktivnost posljednjih je desetljeća kontinuirano rastao.

Tjelesna je aktivnost bila i ostaje neizostavan biološki podražaj nužan za održavanje struktura i funkcija organa i organskih sustava.

Većina, ako ne i sve adaptacijske promjene, uzrokovane umjerenom učestalošću i intenzitetom tjelesne aktivnosti, djeluju tako da poboljšavaju zdravlje, unapređujući strukturu i/ili funkcionalnu sposobnost odgovarajućeg organa. Mnoge adaptacijske promjene također smanjuju rizik od određenih bolesti ili prekursora bolesti, npr. prekomjerne tjelesne mase ili pretilosti.

Tjelesna neaktivnost, pak, kao nedostatak biološkog podražaja, ima sasvim suprotne učinke i povećava rizik od čitavog niza bolesti.

Tjelesna neaktivnost u narušavanju zdravlja

Atrofija mišića, gubitak jakosti i snage. Sarkopenija, gubitak mišićne mase, jakosti i funkcije povezan sa starenjem, dovodi do slabljenja tjelesne funkcije, povećava rizik od padova, ubrzava gubitak koštane mase i time povećava rizik od osteoporoze. Nedostatak tjelesne aktivnosti bitan je čimbenik pojačanja i ubrzanja razvoja sarkopenije.

Osteoporoza i osteoporotični prijelomi. Tjelesna neaktivnost može utjecati na rizik od osteoporotičnih prijeloma povećavanjem rizika razvoja osteoporoze i rizika od padova.

Osteoartritis. Tjelesna neaktivnost je izravno i neizravno povezana s razvojem i rizikom razvoja osteoartritisa.

Križobolja. Između 70 i 85% ljudi tijekom života iskusi simptome boli, mišićne napetosti i ukočenosti križne i lumbalne regije leđa. U osoba s križoboljom tjelesna neaktivnost pogoršava simptome.

Prekomjerna težina i pretilost. Povećanjem rizika za nastanak pretilosti, kao i povećanjem negativnih posljedica pretilosti, osobito metaboličkih promjena, tjelesna neaktivnost uvelike utječe na negativan zdravstveni učinak pretilosti.

Diabetes mellitus tipa 2. Niz prospektivnih studija dokazao je da tjelesna neaktivnost povećava rizik za razvoj dijabetesa tipa 2 za 20 do 70%.

Hipertenzija. Niska razina opće psihofizičkog dobrog stanja ili pripremljenosti (fitnesa) povezana je s oko 50% većim rizikom za razvoj hipertenzije.

Metabolički sindrom. Smatra se da osoba ima metabolički sindrom ako se u nje modu dijagnosticirati ili više sljedećih simptoma: visok krvni tlak, povišena razina glukoze u krvi, povišena razina triglicerida u plazmi, nizak kolesterol HDL, povećan opseg struka. Važnost tjelesne neaktivnosti u patofiziologiji metaboličkog sindroma proizlazi iz središnje uloge skeletnih mišića u metabolizmu ugljikohidrata i masti.

Koronarna bolest srca. Rizik od koronarne bolesti srca je 30 do 50% veći u tjelesno neaktivnih nego u barem umjereno aktivnih osoba.

Cerebrovaskularna bolest (moždani udar). Brojne studije ukazuju na ulogu tjelesne neaktivnosti kao rizičnog faktora moždanog udara.

Periferna vaskularna bolest. Tjelesna neaktivnost važan je čimbenik za razvoj ateroskleroze, čime utječe i na razvoj periferne vaskularne bolesti.

Rak. Pokazatelji o povezanosti tjelesne neaktivnosti sa 30 do 40% većim rizikom od nastanka karcinoma debelog crijeva vrlo su čvrsti. Nešto manje dosljedni, no ipak dovoljni dokazi pokazuju da tjelesna neaktivnost u pred- i postmenopauzalnih žena povećava rizik od raka dojke za 20 do 30%. Postoje i donekle ograničeni pokazatelji o povezanosti tjelesne neaktivnosti i povećanog rizika za nastanak raka endometrija i prostate.

Ukupna smrtnost. Desecima znanstvenih istraživanja utvrđeno je da tjelesna neaktivnost povećava rizik ukupne smrtnosti populacije, s najvećim udjelom smrtnosti od kardiovaskularnih bolesti.

Tjelesna aktivnost kao protulijek za negativne posljedice tjelesne neaktivnosti

Spektar tjelesnih aktivnosti koje pozitivno utječu na zdravlje kreće se od općenitih, individualnih aktivnosti u svrhu poboljšanja zdravlja do vrlo specijaliziranih, specifičnih, stručno

planiranih i nadziranih medicinskih programa vježbanja.

Mišićna masa, jakost i snaga, sarkopenija. Tjelesna aktivnost koja održava i povećava mišićnu masu i jakost ključna je komponenta za poboljšanje zdravlja, osobito u starijoj populaciji.

Koštana masa, osteoporoza i rizik od fraktura. Zbog povećanja ili održavanja koštane mase i čvrstoće te smanjenja rizika od padova, tjelesna aktivnost predstavlja važan čimbenik u prevenciji osteoporoze i osteoporotičnih prijeloma.

Zglobovi i artritis. Svojim utjecajem na zglobnu hrskavicu i okolne strukture, osobito mišiće, tjelesna aktivnost povoljno utječe na sam zglob.

Križobolja. Rezultati kontroliranih studija pokazuju da redovita umjerena tjelovježba može spriječiti nastanak križobolje.

Vratobolja. Istraživanja pokazuju da tjelovježba koja uključuje jačanje vratnih mišića učinkovito ublažuje tegobe uzrokovane kroničnim bolovima vrata.

Prekomjerna težina i pretilost. Povećanjem potrošnje energije, a time i održanjem energetske ravnoteže, tjelesna aktivnost igra važnu ulogu u prevenciji pretilosti.

Dijabetes tipa 2. Porast tjelesne aktivnosti smanjuje rizik za nastanak dijabetesa tipa 2. Izgleda da je taj učinak povezan s količinom aktivnosti.

Hipertenzija. Pojačana tjelesna aktivnost ima znantne zdravstveno pozitivne učinke vezane uz povišen krvni tlak i njegove posljedice.

Metabolički sindrom. Vježbe aerobnog tipa učinkovite su u ublažavanju i otklanjanju različitih komponenata metaboličkog sindroma u pretile djece i odraslih.

Koronarna bolest srca. Trenutno vrijedi preporuka o bavljenju aerobnim oblicima tjelovježbe umjerenog intenziteta barem 30 minuta većinu dana u tjednu. Preporuka je dijelom donesena na temelju saznanja o učinkovitosti tjelesne aktivnosti u prevenciji koronarne bolesti srca.

Kronično zatajenje srca (insuficijencija). Tjelovježba se prepouča kao dio cjelokupne njege pacijenata sa zatajenjem srca.

Cerebrovaskularna bolest (moždani udar). Tjelesna aktivnost učinkovita je mjera u prevenciji moždanog udara.

Periferna arterijska bolest (Claudicatio intermittens). Tjelovježba, pogotovo nadgledano pješačenje, vrlo je učinkovita u liječenju i sekundarnoj prevenciji ove bolesti. Duljina hodanja bez nastupa bolova prosječno se produžava za 150%.

Rak. Trenutačno nije poznato u kojoj bi točno mjeri tjelesna aktivnost mogla umanjiti rizik od određenih vrsta zloćudnih bolesti, kao ni koja bi "doza" tjelesne aktivnosti za to bila odgovarajuća. Najrazboritija je preporuka o redovitoj tjelesnoj aktivnosti umjerenog intenziteta nekoliko puta tjedno, svaki put u trajanju od najmanje pola sata.

Slabljenje kognitivnih sposobnosti povezano sa starenjem. Tjelovježba se može smatrati i oblikom "gimnastike za mozak", osobito ako je raznovrsna te ako zahtijeva i razvija motoričke vještine.

Zaključna poruka

Trenutna znanstvena saznanja uvjerljivo pokazuju da tjelesna neaktivnost, koja je u različitom stupnju prisutna u najvećem dijelu populacije većine svjetskih zemalja, predstavlja ozbiljnu opasnost za zdravlje, funkcionalnu sposobnost i kvalitetu života.

Taj se negativan utjecaj pojačava neodgovarajućom prehranom i drugim faktorima povezanima s prevladavajućim načinom (sedentarnim) života u industrijaliziranim zemljama, a sve više i u zemljama u tranziciji, ali i u zemljama u razvoju.

Iako pravi lijek za negativne učinke tjelesne neaktivnosti (antidot), tjelesna aktivnost još uvijek, nažalost, uvelike pripada privatnoj, individualnoj sferi. Ipak, na društvu je i državi odgovornost da pruži prave informacije o važnosti redovite tjelovježbe te da osigura uvjete i proširi mogućnosti za sigurno bavljenje raznim tjelesnim aktivnostima.

ADAPTATION TO SUBMAXIMAL PHYSICAL TRAINING

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Review
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Abstract:

Submaximal training can induce adaptational changes in the skeletal muscles, cardiovascular system, respiratory system, endocrine system, etc. Knowledge of the signs of adaptation and its magnitude, the factors causing it, as well as an awareness of the significance of the adaptation for the improvement of physical capacity to exercise is essential to develop an optimal training programme and with an adequate recovery process to achieve the maximum positive effect with the minimum negative effect on the athlete's health. Body adaptation resulting from regular aerobic training can involve adaptation of the muscle enzyme systems, changes in the vascularization and type characteristic of muscle fibers, metabolic changes in the trained muscles and muscle groups related to the glucose utilization and the use of glycogen and fats as sources of energy, changes in the blood, the immune and coagulation status of the body, as well as changes in the parameters of aerobic working capacity of the organism. Regular submaximal exercises have been found to increase the activity of key oxidative enzymes in the metabolic pathway for the breakdown of carbohydrates - hexokinase (HK) and citrate synthase (CS) and fats – 3-hydroxyacyl-CoA dehydrogenase (3-HAD) and carnitine palmitoyltransferase (CPT) and in the respiratory chain citochrome *c* oxidase (CCO). Submaximal training induces vascularization in the muscles containing predominantly oxidative muscle fibers. The muscle fibers in the groups of muscles trained submaximally can even undergo a type transformation. The insulin-mediated glucose transport in the cells of the recruited muscles is selectively increased. A metabolic adaptation occurs as the body shifts from using carbohydrates for energy to using fats; the subsequent "glycogen-sparing" effect enhances the working capacity. Permanent changes occur in the humoral immunity evidenced by the increase of the serum IgA and IgG concentrations. The system of oxygen transport in the blood adjusts to more economical operation. As a final result both the external system of oxygen delivery and the mitochondrial system of oxygen utilization undergo adaptation which leads to a moderate increase of maximal oxygen consumption, but greater increase of the oxygen running economy.

Key words: *submaximal exercise, adaptation, athletes, aerobic working capacity*

ADAPTATION AN DAS SUBMAXIMALE KÖRPERLICHE TRAINING

Zusammenfassung:

Das submaximale Training kann Anpassungsänderungen sowohl in Skelettmuskeln, im Herz-Kreislauf- und Atmunssystem und im Endokrinium als auch in anderen Systemen verursachen. Sowohl das Kenntnis der Adaptationszeichen und des Adaptationsausmaßes, sowie das Kenntnis der zugrundeliegenden Faktoren, als auch das Bewußtsein über die Wichtigkeit der Adaptation für die Verbesserung der körperlichen Leistungsfähigkeit sind unentbehrlich, um ein optimales Trainingsprogramm zu entwerfen, und mit einem angemessenen Erholungsprozess einen maximal positiven Effekt mit einer minimal negativen Auswirkung auf die Gesundheit des Sportlers zu erzielen.

Die Körperadaptation, als Folge eines regelmäßigen aeroben Trainings, umfasst die Anpassung der Muskelenzymsysteme, Änderungen der Vaskularisation und der Muskelfaserart, Stoffwechselveränderungen in trainierten Muskeln und Muskelgruppen, die mit Glukoseverbrauch verbunden sind, den Verbrauch des Glykogens und der Fette als Energielieferanten, Veränderungen im Blut, im Immunsystem und Koagulationsstatus des Körpers, sowie die Veränderungen von Parametern der aeroben Kapazität des Organismus unter Belastung.

Es wurde festgestellt, dass regelmäßige submaximale Übungen die wesentlichen oxidativen Enzymen in Soffwechselprozessen fördern, die für die Aufspaltung von Kohlenhydraten - Hexokinase (HK) und Zitrat-Synthase (ZS), von Fetten – 3-Hydroxyacyl-CoA- Dehydrogenase (3-HAD) und Karnitin-Palmitoyl-Transferase (KPT) und Zitokrom c-Oxidase (ZCO) im Respirationstrakt verantwortlich sind. Das submaximale Training ruft Vaskularisation in den aus überwiegend oxidativen Muskelfasern bestehenden Muskeln hervor. Die Muskelfasern in den submaximal trainierten Muskelgruppen können sogar eine

Typentransformation erleben. Der Insulin vermittelnde Glukosentransport in den Zellen der betroffenen Muskeln nimmt selektiv zu. Die metabolische Adaptation findet statt, wenn der Körper die Kohlenhydrate mit Fetten als Energielieferanten ersetzt; der nachfolgende "Glykogen-Schonungseffekt" vergrößert die Arbeitsfähigkeit. Die humorale Immunität wird endgültig geändert, was an der Zunahne der IgA and IgG Serumkonzentrationen bemerkbar ist. Der Sauerstofftransport im Blut wird einer ökonomischeren Wirkung angepasst. Das Endergebnis ist die Veränderung sowohl von dem äußeren System des Sauerstoffzufuhrs als auch von dem mitochondrialen System des Sauerstoffverbrauchs, was nicht nur zu einer mäßigen Zunahme des maximalen Sauerstoffverbrauchs führt, sondern auch zu der Steigerung der Sauerstoffverbrauchsökonomie.

Schlüsselwörter: *submaximale Bewegungsübungen, Adaptation, Sportler, aerobe Kapazität unter Belastung*

Introduction

A training exercise, methodologically properly performed and conducted regularly at submaximal levels (with an intensity which requires oxygen consumption of about 65-75% of VO_2max), is a major way to create structural and functional bases to achieve a high aerobic working capacity (Wilmore & Costill, 1999). This type of training causes adaptational changes in the skeletal muscles (increased activity of key oxidative enzymes), in the cardiovascular, respiratory, and endocrine systems which lead to a greater aerobic working capacity (increased maximal oxygen uptake and submaximal endurance) and hence to an improvement in sports results (Boyadjiev, 1996a). To know these changes, their scope, and the direct factors causing them gives you a powerful means to gain, through an optimal training plan and adequate recovery under the guidance of a trainer and medical staff, maximum results with a minimum adverse effect on the health of athletes.

Enzyme adaptation in muscles

Endurance training induces a distinct adaptation in the recruited muscles. They can be evaluated both morphologically and biochemically by using biopsy techniques.

It is well known that the major pathways for energy supply to the working muscles are:

- glycolysis / glycogenolysis,
- fatty acid oxidation (beta-oxidation),
- Krebs cycle,
- oxidation in the respiratory chain.

The capacity of these pathways is restricted mainly by the quantity (activity) of key enzyme active there. An increase of the quantity (activity) of some of these key enzymes can theoretically increase the capacity of the entire metabolic pathway with the activity of other enzymes (inactive in this pathway) remaining unchanged (Newsholme & Leech, 1983).

It is worth noticing here that the changes in the metabolic pathway capacity (increasing as a result of training or decreasing as a result of detraining) occur simultaneously with the changes in quantity (activity) not only of the key enzyme but also of the other enzymes of the pathway. For example, as a result of chronic (10-week) stimulation of rabbit's muscles the activity of succinate dehydrogenase (SDH) and citrate synthase (CS) in m. soleus increases linearly for three weeks to respectively 600% and 300% of baseline levels, and then starts decreasing until the 10th week to 250% and 150% of the baseline values (Figure 1).

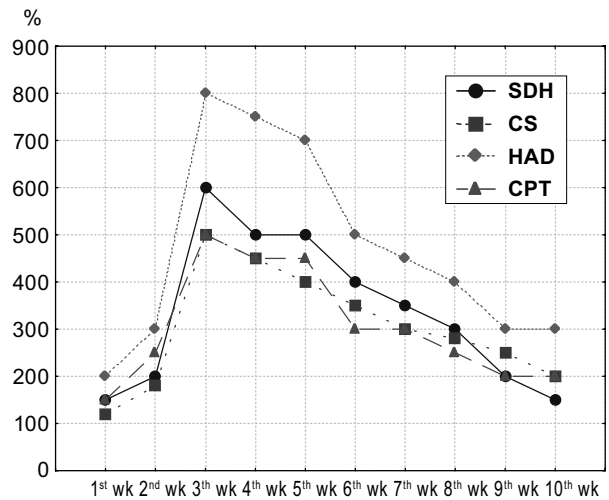

Figure 1. Enzyme activity changes (% of initial level) as a result of muscle electrostimulation in experimental rabbits.

Choosing a group of enzymes to use in the analysis depends largely on the biochemical techniques mastered for their detection in muscle homogenates; basically, the following enzymes are used:

- hexokinase (HK) and lactate dehydrogenase (LDH) in the assessment of the glycolytic pathway,
- 3-hydroxyacyl-CoA dehydrogenase (3-HAD) and carnitine palmitoyltransferase (CPT)

in the analysis of beta-oxidation of fatty acids,
- citrate synthase (CS) in the analysis of Krebs cycle,
- cytochrome c oxidase (CCO) for the assessment of the respiratory chain.

The enzymes in the Krebs cycle and fatty acid beta-oxidation are usually defined as oxidative. The maximal change due to regular submaximal training (7- to 10-fold increase) occurs in the period between weeks 3 and 5 (Boyadjiev, 1996b). After cessation of training their activity drops to baseline levels after 5 to 6 weeks.

While studies on muscle tissue enzymes of experimental animals had been performed even by 1970, human studies of biopsic material were not performed until 1970 and 1971 (Morgan, Cobb, Short, Ross, & Gunn, 1971; Vernauskas, Bjorntorp, Fahlen, Prerovsky, & Sternberg, 1970). From 1970 to 1980 the techniques for obtaining biopsic material as well as the methods for its processing (buffering, organelle disintegration, etc) were perfected. The changes are differently expressed in experimental animals and people but in all cases they are similar (Figure 2 and Figure 3).

The explanation that enzyme adaptation occurs as a result of submaximal training can be explained by the fact that the enzymes have a specific "life cycle" and, accordingly, each has a specific half-life, which varies from 1 week (for the mitochondrial enzymes) to 1 day (for the glycolytic enzymes). The cellular content (the metabolic activity) of the enzyme is always a result of the balance between its synthesis and its disintegration. The submaximal workload affects the intensity of enzyme synthesis (Williams, Salmons, Newsholme, Kaufman, & Mellor, 1986). The following is believed to be at the basis of the enzyme adaptation:
- reduced content of ATP and/or of other high-energy phosphates in the cell,
- reduced O_2 pressure in the muscle tissue,
- increased sympathoadrenal stimulation of the muscle cell,
- Ca-induced release of diacylglycerol with ensuring activation of protein kinase C.

Changes in the vascularization of the trained muscles

Regular aerobic exercise leads to an almost two-fold increase of the number of capillaries per unit of muscle cross-sectional area which results in the increase of the blood flow rate through the working muscles. This can take as long a time as it takes for the enzyme adaptation to occur - for two months vascularization can increase by about 50%, sometimes even two- or threefold.

In a study on rats Dudley, Abraham and Terjung (1982) found that the effect exerted by aerobic exercises on muscles differs for the different types of muscle fibers. In fast oxidative glycolytic fibers (type IIa or FOG) the effect enhances with the increase of training intensity up to intensities equaling 80% of VO_2max. Fast glycolytic fibers (type IIb or FG) can be affected by regular exercises at intensity over 80% of VO_2max. The effect for the slow fibers of type I is better pronounced in higher intensity of training up to 80% of VO_2max. In intensities higher than this the effect is less pronounced.

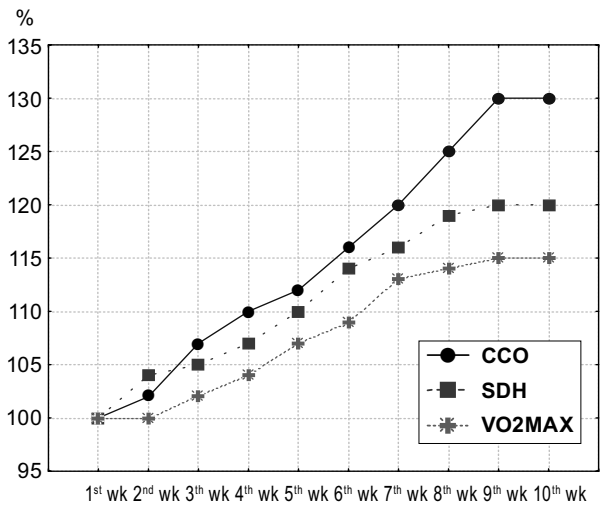

Figure 2. Enzyme adaptations as a result of submaximal training in m. vastus lateralis in humans.

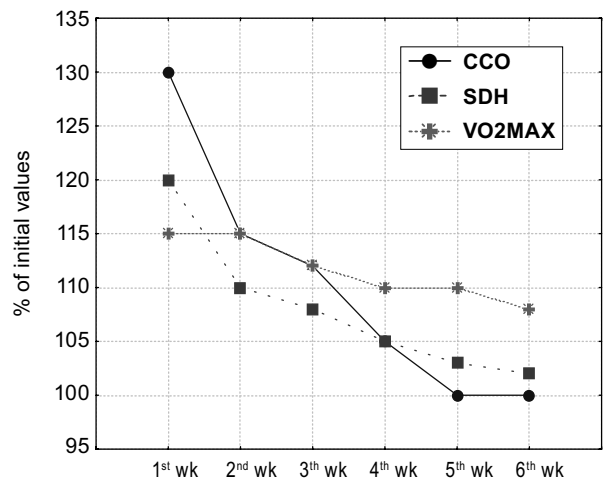

Figure 3. Changes in the activity of CCO, SDH and maximal oxygen uptake after ceasing training procedures in humans.

Changes in the type characteristic of muscle fibers

There are basically two types of muscle fibers - type I (slow-twitch or ST) and type II (fast-twitch or FT). Type I muscle fibers have high oxidative capacity, that is, high activity of the oxidative enzymes. Type II fibers are characterized by relatively higher glycolytic capacity and lower resistance to fatigue than type I fibers. In submaximal exercises, the lactate produced in the muscles is oxidized by type I fibres but utilized by type II fibers for glycogen resynthesis. This difference in the metabolic "behavior" of the two types of muscle fibers is due to the relative difference in the activity of the glycolytic system in the cytosol and the oxidative enzyme system in the mitochondria as well as to the differences in the activity of the enzymes responsible for glycogen resynthesis. For example, in systematic endurance training in type I fibers the activity of the H-LDH (heart specific isoenzyme) increases.

Fast-twitch fibers (type II) have a high degree of myosin-ATPase activity; they can rapidly release Ca^{++} and realize fast glycolysis. The slow-twitch fibers (type I) have a low myosin-ATPase activity, lower glycolytic capacity, greater amount of mitochondria and myoglobin and higher oxidative capacity. Type IIa fibers actually represent a transition type of fibers because although fast, they have a higher activity of the enzyme SDH (that is, they have aerobic capacity). Type IIb are typical fast-twitch fibers. There are also type IIc fibers which are few and undifferentiated.

While enzyme activity of the recruited muscles can change relatively rapidly as a result of regular training, the distribution of fibers within the active muscle probably remains constant. However, this is at present a controversial matter. Noakes (1992) reports in a study that the gastrocnemius muscle in long distance runners is composed of about 79% of type I fibers, in middle distance runners - of about 62%, and in untrained subjects - 58%. Similar data are also reported by other authors, the differences in the fiber distribution being genetically determined according to Komi, Viitasalo, Havu, Thorstensson, Sjodin and Karlsson (1977) and Komi and Karlsson (1979) (Figure 4).

We should keep in mind that it is type I fibers (the slow-twitch fibers) that are initially activated in continuous submaximal exercises.

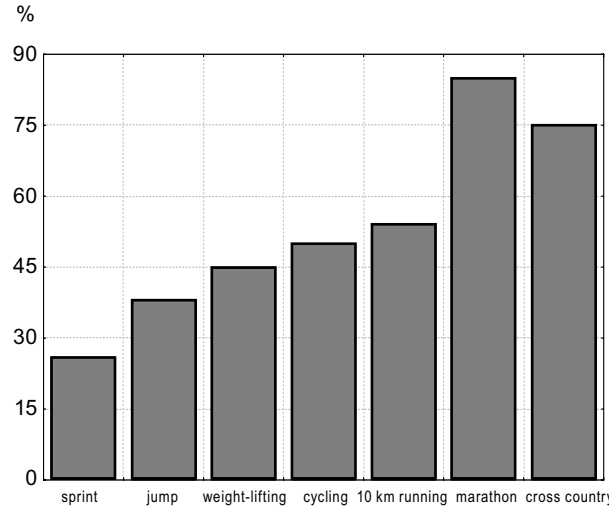

Figure 4. Muscle fibers of type I in m. gastrocnemius (%) in athletes of different sports.

When, however, the energy stores in them are close to depletion, a larger number of fast-twitch fibers (type II) begins to be recruited, first type IIa, then type IIb (Saltin, 1981).

Some authors indicate that conversion from one type of muscles to another as a result of training is impossible to occur in humans (Gollnick, Armstrong, Saubert, Sembrowich, Shepherd, & Saltin, 1973; Saltin & Gollnick, 1983). Other researchers have opposite findings suggesting that with the metabolic and physiological potential of muscle fibers it is quite possible to underage transformation (Aitken, Bennet, & Thompson, 1989; Bell, MacDougall, Billeter, & Howald, 1980; Pete & Vrbova, 1985; Tesch & Karlsson, 1985). There are also authors that regard as possible only the conversion of type IIb fibers to type IIa (Andersen & Henriksson, 1977; Jansson & Kaijser, 1977).

Changes associated with glucose utilization from muscle cells. The role of insulin.

It is well known that the transmembrane glucose transport is realized by facilitated diffusion in the muscle cells, the adipocytes and the fibroblasts. This is a passive process (glucose is taken up from a place with high concentration and transported to a place with low concentration) mediated by a carrier molecule which facilitates the glucose transport through the membrane. Therefore, in the course of transportation, the carrier will have a certain degree of saturation. In skeletal muscles the Michaelis constant (Km) for the

glucose transport from the external to the internal side of the cellular membrane is 5-10 mmol. Research has shown that this transport is stimulated by the increased contractility (leading to an elevated release of intracellular Ca^{++}) and insulin. The direct Ca^{++} effect persists several hours after exercise while the effect from insulin lasts one or two days. It is interesting to note that the insulin effect applies to those group of muscle that are recruited in the training (Essen, Hagenfeldt & Kaijser, 1977). It has been found that the glucose transport in submaximal exercises is selectively increased in the slow-twitch muscle fibers (Ploug, Stallknecht, Pedersen, Kahn, Ohkuwa, Vinten, & Galbo, 1990). Rodnick, Reaven, Azhar, Goodman and Mondon (1990) have found that aerobic training leads to the increase of glucose transporters in the membrane of the slow-twitch muscle fibers. In already trained people the response to insulin is more markedly pronounced in this respect. Therefore, regular submaximal exercises cause the sensitivity of the muscle cells to insulin to increase.

Changes in muscle glycogen

In trained people at rest, the glycogen concentration in their muscles is higher than that of untrained subjects (140 - 230 mmol/g ww vs. 70 -110 mmol/g ww). Identical relationship is found in comparing a trained with an untrained extremity of one and the same individual. In the process in detraining the glycogen content becomes equal in both extremities. Mikines, Sonne, Tronier and Galbo (1989) have found that in trained subjects the activity of the enzyme glycogen synthase in the muscle cells is high, while Bogardus, Ravussin, Robbins, Wolfe, Horton and Sims (1984) and Devlin and Horton (1985) have demonstrated that this enzyme enhances its activity under the effect of insulin. Therefore, the repletion of glycogen stores after a submaximal exercise is associated with an increased sensitivity of the muscle cell to insulin. According to Gulve, Cartee, Zierath, Corpus and Holloszy (1990) this intensifies the process of glucose uptake into the cell.

When the exercise performed at 60 to 80% of the maximal oxygen consumption continues for more than 60 minutes, the initial glycogen concentration in muscles is undoubtedly crucial for the submaximal endurance (which is an element of the aerobic work capacity of the body). The rapidness with which fatigue is felt is the major limiting factor for submaximal endurance. It is directly proportional to the degree of muscle glycogen depletion (ΔG) in the process of the performed work. When an alternative substrate for aerobic oxidation (fatty acids) is available we have a "glycogen sparing effect" which occurs during exercise which leads to a delay of fatigue and eventually to an increase of the submaximal endurance. The glycogen sparing effect usually occurs after 6 weeks of regular aerobic training and is mainly caused by enzyme adaptation in the beta oxidation pathway (CPT). The capillarization additionally facilitates this process. Thus it turns out that trained individuals can utilize fatty acids in submaximal exercices as a sourse of energy better than untrained subjects can which leads to a preservation of the supplies of glycogen and hence to greater endurance in an identical intensity of performed work. The respiratory exchange ratio (RER) in trained people is lower than that in untrained people; they have also a higher degree of utilization of muscle triglycerides (Figure 5).

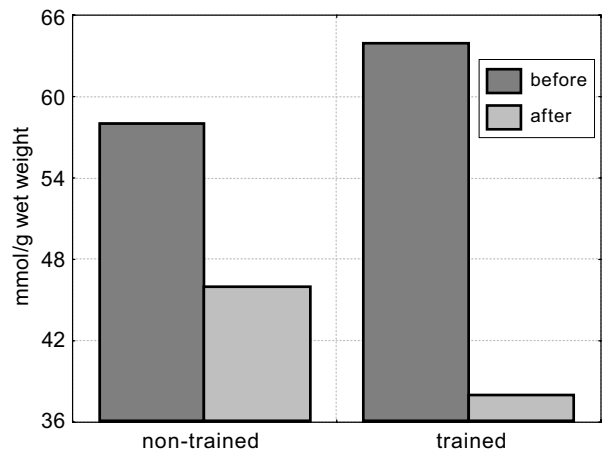

Figure 5. Muscle triglycerides before and after workload (64% of VO_2max) in trained and non-trained state.

In a previous study on 233 rowers training for more than 3 years we found that the total serum cholesterol (means ± SD) was lower than that of age-matched non-trained controls (3.90±0.76 versus 4.31±0.76 mmol/l; $p < 0.001$); no differences between the serum triglycerides of these groups were found (Taralov, Boyadjiev, & Georgieva, 2000).

In summary, the mechanisms leading to an enhanced fatty oxidation due to training are:

- increased lipolysis of available triglycerides in the muscles,
- enhanced transport of fatty acids in the mitochondria,

- increased number of mitochondria in the muscle cells,
- increased activity of the mitochondrial enzymes in beta-oxidation (3-HAD and CPT),
- increased sympathoadrenal activity.

Immunity

It is well known that physical activity affects the body's immune system. Submaximal exercises are considered to stimulate both the nonspecific and the specific immunity which reduces the risk of inflammatory diseases. There have been studies, however, which demonstrate that immunodepression can be caused by intensive exercise training and accompanied by an increased morbidity rate of infectious diseases, especially acute respiratory infections (Pedersen, Rohde, & Zacho, 1996; Pyne & Gleeson, 1998).

It is widely thought that a single-bout exercise can reduce immune reactivity, while a regular submaximal exercise training going on for many years can have a heterogeneous effect on the parameters of the immunity and the systemic inflammatory response. In a study including 143 rowers from sports schools in Bulgaria (age 14.01±0.06 yrs; 56.35±0.49 kg; 3.44±0.06 yrs of training, training 5 days per week, two times a day) and 61 untrained controls (age 14.12±0.09 yrs; 57.01±0.23 kg) we found that the mean serum concentration of Ig A in the athletes was by 47.5% higher ($p < 0.001$), of IgM - by 22.0% lower ($p<0.001$), and of IgG - by 10.7% higher ($p<0.05$) than those of the untrained individuals (Table 1, data presented as mean ± SEM) (Taralov, Boyadjiev, & Georgieva, 1999).

Table 1. Serum immunoglobulin profile in submaximal trained and non-trained pubescent subjects (mean±SEM)

VARIABLE / GROUP	IgA (g/l)	IgM (g/l)	IgG (g/l)
1. rowers (n=143)	2.05±0.07	0.96±0.03	12.24±0.32
2. controls (n=61)	1.39±0.10	1.23±0.09	11.06±0.44
P1-P2	0.001	0.001	0.05

Adaptations in the oxygen transport system - red blood

Biancotti, Caropreso, Di Vincenzo, Ganzit & Gribaudo. (1982) and Hasibeder, Schobesbarger and Mairbaurl (1987) demonstrated that intense training, which includes also submaximal training, could lead to a "suboptimal" hematologic status of athletes, with evidence even in some cases of sports anemia. In a previous study we examined 230 rowers (122 boys and 108 girls) of sports schools in Bulgaria (age 14.01±0.06 yrs; 56.24±0.52 kg; 3.52±0.07 yrs of training, training 5 days per week, two times a day) and 350 untrained controls (168 boys and 182 girls – 14.58±0.09 yrs, 57.75±0.67 kg). The findings of the study indicate that with the number of years of increased training the athletes undergo certain adaptations which create the conditions for a greater economy and effectivity of

Table 2. Red blood cell variables in submaximal trained boys (rowers) compared with non-trained controls (mean±SEM)

VARIABLE / GROUP	RBC (x 10^{12}/l)	Hct (l/l)	Hb (g/l)	MCV (fl)
1. rowers (n=122)	4.66±0.03	0.400±0.003	136.21±0.94	85.59±0.39
2. controls (n=168)	5.01±0.03	0.425±0.003	146.16±0.82	84.94±0.40
P1-P2	0.001	0.001	0.001	NS

RBC, red blood cell count; Hct - packed cell volume; Hb - haemoglobin; MCV - mean corpuscular volume.

Table 3. Red blood cell variables in submaximal trained girls (rowers) compared with non-trained controls (mean±SEM)

VARIABLE / GROUP	RBC (x 10^{12}/l)	Hct (l/l)	Hb (g/l)	MCV (fl)
1. rowers (n=108)	4.32±0.04	0.364±0.003	124.27±0.93	86.00±0.45
2. controls (n=182)	4.51±0.03	0.384±0.002	134.26±0.64	85.51±0.44
P1-P2	0.001	0.001	0.001	NS

RBC, red blood cell count; Hct - packed cell volume; Hb - haemoglobin; MCV - mean corpuscular volume.

the oxygen transport with blood - the increased demands of athletes doing submaximal exercises are met by a smaller number of red blood cells (RBC), a smaller amount of hemoglobin (Hb) and lower hematocrit (Hct) in the peripheral blood; for boys these parameters are by 7.5%, 7.5% and 6.2%, respectively, lower than the corresponding parameters in the untrained subjects ($p<0.001$); for girls the parameters are lower by 4.5%, 8.0% and 5.5%, respectively ($p<0.001$). The mean corpuscular volume (MCV) in both groups and both genders was identical (Tables 2 and 3) (Boyadjiev & Taralov, 2000).

Adaptation in the blood coagulation system

Physical exercise and training induce changes in the hemostasis of healthy people. A single bout of exercise usually causes transitory activation of the coagulation system indicated by a shortening of the activated partial thromboplastin time (APTT) (Bartsch, Haeberli, & Straub, 1990; El-Sayed, Sale, Jones, & Chester, 2000; Prisco et al., 1998) or by activation of the fibrinolytic mechanisms (Wallen, Goodall, & Hjemdahl, 1999). There are few studies on the long-term effects of doing of different types of exercises on coagulation. We conducted a study of 37 active training athletes exposed to submaximal workloads (age 15.49±2.02 yrs, 4.83±2.20 yrs of training); when the findings from these athletes were compared with those of 67 age-matched controls (15.81±2.73 yrs) no differences were found between the basal values of the major coagulation parameters - number of thrombocytes (PLT), fibrinogen (FGN), prothrombine time (pT), activated partial thromboplastin time (APTT) and thromboplastin time (TT). Unlike these subjects, the athletes doing anaerobic sports for a long time show the parameters suggestive of activation of the blood coagulation mechanisms which is persistently more intense, a characteristic consequence in untrained people exposed to acute workload (Table 4) (Boyadjiev & Taralov, 2002).

Table 4. Haemocoagulation parameters in strength and endurance athletes compared with non-trained controls (mean±SD)

VARIABLE / GROUP	PLT ($x\ 10^9$/l)	FGN (g/l)	pT (%)	APTT (s)	TT (s)
1. strength (n=46)	278.8±52.9	2.79±0.69	86.12±10.47	31.25±2.21	20.63±1.24
2. endurance (n=37)	256.9±44.9	2.65±0.61	81.00±9.50	31.46±2.76	21.30±2.75
3. controls (n=67)	270.6±49.7	2.47±0.58	80.78±10.09	31.96±2.69	21.53±1.30
P1-P2	0.05	NS	0.05	NS	NS
P1-P3	NS	0.02	0.02	NS	0.001
P2-P3	NS	NS	NS	NS	NS

PLT - platelet count; FGN - fibrinogen; pT - prothrombin; APTT - activated partial thomboplastin time; TT - thromboplastin time.

Changes in the parameters of aerobic work capacity

Aerobic work capacity depends on the ability of the body to provide energy for muscle activity through the aerobic mechanisms of oxidation; it is characterized by:

- aerobic power (oxygen consumption under physical stress or VO_2max),
- submaximal endurance.

Although it is a very important parameter, VO_2max should not be considered in isolation when assessing aerobic working capacity. It is quite possible, for instance, for two elite long distance runners to have an identical performance, with the one having high VO_2max and relatively poorer utilization of oxygen, and the other - lower VO_2max but more economical use of oxygen under physical stress. It has been found that athletes showing similar results can have rather different VO_2max. Therefore, important as this parameter can be, it is not crucial for a sports person's achievement. The factor that matters here is what percentage of the athlete's own VO_2max can be used in performing specific physical work. Daniels (1974) and Costill (1979) established independently that different athletes have an identical running speed in a competition but at a different percentage of their maximal oxygen consumption. Better athletes run using smaller amounts of oxygen, that is, they have greater running economy.

VO_2max reflects to a large extent the oxygen transport and oxygen delivery to working muscles. While in untrained subjects it can be in

the range of 40 to 55 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$, in elite athletes it can reach values of up to 77 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ and even 90 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$. VO_2max is genetically determined and with the development of the individual it can be raised through training by 5-15% (Figure 6).

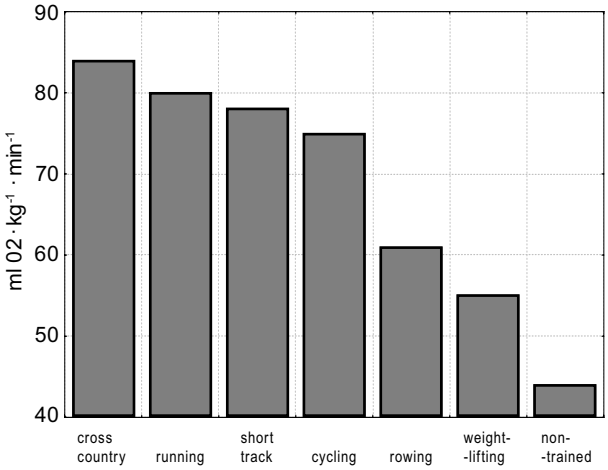

Figure 6. VO_2max of male elite sports people of different sports.

What changes take place in aerobic capacity with age have been shown in the longitudinal studies of Trappe, Costill, Vukovich, Jones and Melham (1996) on a contingent of elite sports people. The survey started in the 1960s and lasted till the last decade of the millenium. A marked reduction of VO_2max (over a period of 20 years) was found in a group of athletes that had stopped training - decrease by 18% in the absolute maximal oxygen consumption and by 34% in the relative consumption because of weight gain. In those that kept on training this reduction was 9% and 14%, respectively. Biopsy specimens were taken from m. gastrocnemius in all subjects. The findings showed that the former active athletes who went on training intensively had high activity of the mitochondrial enzymes CS and SDH while those who had ceased to train had a considerable decline of the activity of the oxidative enzymes which was most probably the cause for the pronounced reduction of VO_2max in them.

It is important to bear in mind the fact the maximal oxygen consumption is dependent on two systems:

- an "external" system of oxygen delivery which includes the cardiorespiratory system and blood - it delivers oxygen from the air to the muscle cell,
- an internal (mitochondrial) oxygen utilization system realizing the aerobic production of energy.

What is the restricting factor for VO_2max? This issue is quite controversial among sports physiologists. It is believed that muscle capacity for oxygen utilization is several times as high as (or at least it acquires this characteristic as a result of aerobic training) the capacity of the cardiorespiratory system to meet its demands. For this reason the changes occurring in the cardiovascular system and especially the increase of the stroke volume and the cardiac output are very important for the enhancement of the aerobic capacity of the body as a result of regular submaximal exercise.

Conclusions

The adaptational changes in the body we and other authors have found that result from submaximal exercises can be summarized as follows:

1. Key oxidative enzymes in the carbohydrates breakdown pathway (HK and CS), in the fat breakdown pathway (3-HAD and CPT) and in the respiratory chain (CCO) increase their activity.
2. A selective vascularization in the muscles containing predominantly oxidative muscle fibers is induced.
3. A type change of the muscle fibers is possible to occur (including changes from type II to type I) in the submaximally recruited muscle groups.
4. Glucose transport in the cells of the recruited muscles is selectively increased with direct insulin mediation.
5. A metabolic adaptation occurs which consists of a shift in the energy substrates from carbohydrates to fats and a subsequent glycogen sparing effect which guarantees a delay of fatigue and an increase of the work capacity. The serum level of the total cholesterol decreases permanently.
6. Permanent changes occur in the humoral immunity expressed as an increase of the level of serum IgA and IgG.
7. The system of oxygen transport in blood adapts to a more economic operation. The coagulation capacity of blood does not differ from that of untrained subjects.
8. Eventually, adaptation of the external system of oxygen delivery and the mitochondrial system of oxygen utilization occurs which has as a result an insignificant increase of the maximal oxygen consumption and a significant increase of the oxygen running economy.

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ADAPTACIJA NA SUBMAKSIMALAN FIZIČKI TRENING

Sažetak

Submaksimalan trening može potaknuti adaptacijske promjene skeletnih mišića, kardiovaskularnog sustava, respiratornog sustava, endokrinog sustava itd. Poznavanje obilježja i veličine adaptacije, poznavanje čimbenika koji je uzrokuju, kao i svijest o važnosti adaptacije za poboljšanje fizičkih sposobnosti neizostavni su za oblikovanje optimalnog trenažnog programa te, uz adekvatan proces oporavka, za postizanje maksimalnog pozitivnog učinka uz minimalan negativni učinak na zdravlje sportaša.

Adaptacija, kao posljedica redovitog aerobnog treninga, može uključivati adaptaciju enzimskih sustava mišića, promjene u vaskularizaciji i tipu mišićnih vlakana, metaboličke promjene treniranih mišića i mišićnih skupina povezane s korištenjem glukoze i uporabom glikogena i masti kao izvora energije, promjene u krvi, imunološki i koagulacijski status, kao i promjene parametara aerobne radne sposobnosti organizma.

Adaptacijske promjene u tijelu, za koje smo i mi i drugi autori utvrdili da su posljedica submaksimalnih vježbi, moguće je sažeti ovako:

1. Pojačava se aktivnost ključnih oksidacijskih enzima u procesu razgradnje ugljikohidrata (HK i CS), u procesu razgradnje masti (3-HAD i CPT) i u respiracijskom lancu (CCO).
2. Inducirana je selektivna vaskularizacija u mišićima koji pretežno sadrže oksidacijske mišićna vlakna.
3. Kod submaksimalno aktiviranih mišićnih skupina može nastati promjena tipa mišićnih vlakana (uključujući prelazak iz tipa II u tip I).
4. Direktnim djelovanjem inzulina selektivno se povećava prijenos glukoze u stanice aktiviranih mišića.
5. Dolazi do metaboličke adaptacije koja se očituje u premještanju energetskih procesa s ugljikohidrata na masti s posljedicom uštede glikogena, što jamči odgodu pojave zamora i porast radne sposobnosti. Nastupa i trajni pad razine ukupnog kolesterola u serumu.
6. Trajne promjene humoralnog imuniteta izražene su u vidu porasta razine IgA i IgG u serumu.
7. Sustav prijenosa kisika krvlju prilagođava se u smislu povećanja ekonomičnosti. Koagulacijski kapacitet krvi ne razlikuje se od istog kapaciteta netreniranih osoba.
8. Konačno, prisutna je i adaptacija vanjskog sustava za dopremu kisika i mitohondrijskog sustava iskorištenja kisika, što za posljedicu ima neznačajan porast maksimalnog primitka kisika i značajno poboljšanje ekonomike potrošnje kisika (energetske učinkovitosti).

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