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IMPACT OF REGULAR RUNNING ON HEALTH: ADAPTATIONS OF THE CARDIOVASCULAR AND MUSCULOSKELETAL SYSTEMS – A LITERATURE REVIEW

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ABSTRACT

Introduction/Aim: Regular physical activity, such as running, is considered one of the most accessible forms of exercise with well-documented health benefits. This review aims to present current knowledge on the effects of regular running on health and discuss the physiological adaptations it induces, particularly in the cardiovascular and musculoskeletal systems.
State of knowledge: Numerous studies confirm that regular running results in multidimensional health benefits. Cardiovascular adaptations include improved aerobic capacity, lower resting heart rate, and beneficial cardiac remodeling. Running also induces changes in the musculoskeletal system: increased capillary density and muscle mitochondrial content enhance endurance. In contrast, higher bone mineral density strengthens the skeleton and contributes to osteoporosis prevention.
Summary/Conclusions: Running is an effective, accessible, and versatile form of physical activity that promotes health in multiple domains. Long-term, regular running leads to beneficial adaptations in the cardiovascular and musculoskeletal systems, reducing the risk of chronic diseases and improving quality of life.

KEYWORDS

Running, Jogging, Health, Cardiovascular Diseases, Musculoskeletal Injuries

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1. Introduction

Running has become one of the most popular forms of physical activity. Social media are filled with messages extolling the virtues of this sport, and street races, marathons, and sports events for adults and children are organized worldwide. Numerous running clubs are emerging, uniting amateur runners who can train together, share experiences, and motivate each other. Every regular physical activity has beneficial health effects, but because of its low cost and easy accessibility, running is the choice of millions of people of all ages [1].

Regular running brings several documented health benefits: for example, it improves overall endurance and cardiovascular fitness and helps reduce risk factors for many lifestyle diseases. Studies have shown, for instance, that recreational runners are less likely to suffer from obesity, hypertension, lipid disorders, or type 2 diabetes [2,3]. Running triggers a series of adaptive mechanisms in the body, allowing it to adjust to the increased demands for energy and oxygen. These changes affect practically all systems: respiratory, cardiovascular, musculoskeletal, and metabolic. Understanding these adaptations is important from the standpoint of exercise physiology, preventive medicine, and rehabilitation.

The article aims to present the current knowledge regarding running's positive impact on health, particularly emphasizing runners' physiological adaptive mechanisms. The review primarily discusses cardiovascular and musculoskeletal system adaptations and their health-related significance.

2. Materials and Methods

This work is a review based on the analysis of available scientific studies regarding the impact of running on health. We searched the PubMed, Google Scholar, ScienceDirect, and Medline databases using the keywords: *running, jogging, health, cardiovascular diseases, and musculoskeletal injuries*. The search was limited to publications from 2008 to 2025, covering adult populations – recreational and competitive runners. Original studies, review articles, meta-analyses, and case reports were included in the analysis.

Studies focusing on the effects of regular (long-term) running training on the physiology of the cardiovascular, musculoskeletal, or metabolic systems were included as inclusion criteria for publications. The collected material was analyzed by critically evaluating study results and extracting common conclusions concerning the described adaptive mechanisms.

The collected data were thematically grouped into cardiovascular and musculoskeletal systems sections. These sections discuss adaptive phenomena associated with regular running observed in the literature.

3. State of knowledge

Current research highlights that regular running promotes beneficial adaptations in the cardiovascular and musculoskeletal systems. These changes enhance endurance, strengthen bones and muscles, and lower the risk of cardiovascular diseases. Below is an overview of key findings from recent studies.

3.1 Cardiovascular System

According to the World Health Organization (WHO), cardiovascular diseases (CVDs) are the most common cause of death worldwide, accounting for about 17.9 million deaths per year (~32% of all deaths). A 2023 World Heart Federation report states that in 2021, as many as 20.5 million people died due to CVD – about one-third of global mortality, an increase of 60% compared to 1990 [4,5]. Runners have a significantly lower risk of heart attack, stroke, and other cardiovascular incidents compared to inactive individuals. A meta-analysis covering many cohort studies showed that participating in running is associated with about a 30% reduction in the risk of death from cardiovascular causes. At the same time, runners have a significantly lower risk of developing ischemic heart disease or hypertension than the general population [6,7].

Regular physical exercise lowers resting heart rate, reduces blood pressure, and lowers atherosclerotic markers, while also leading to a favorable, physiological enlargement of the heart muscle [8]. Systematic training improves myocardial perfusion and increases the level of the "good" high-density lipoprotein (HDL) cholesterol, which together reduce cardiac workload and enhance cardiovascular function, both in healthy individuals and those suffering from cardiovascular disease [6, 9]. Endurance runners exhibit enlargement of the left and right ventricular cavities, thickening of the left ventricular wall, and moderate, symmetrical myocardial hypertrophy. These changes result in increased stroke volume and cardiac output, enabling more blood to be pumped with each contraction. This type of remodeling is known as physiological hypertrophy – the heart walls thicken by about 10–20% and chamber volumes increase by roughly 10–15% compared to inactive people [11]. Systolic and diastolic function indicators improve: the athlete's heart pumps blood more efficiently at rest and during exertion. Unlike pathological changes (e.g., hypertrophic cardiomyopathy, where hypertrophy is asymmetrical), the remodeling of the heart muscle in runners is uniform [12].

Over the longer term, regular running training causes a gradual reduction in arterial blood pressure. A stronger heart pumps blood with less effort, which reduces vascular resistance. Studies have noted drops in blood pressure on the order of 4–10 mmHg for systolic and 5–8 mmHg for diastolic pressure, already after 1–3 months of regular training, and this effect persisted in individuals who continued their activity [13]. Endurance training also benefits blood vessels, improving their elasticity and adaptive control of tone. During dynamic exercise such as running, blood flow increases and enhanced shear stress acts on vessel walls, stimulating reflex dilation of arteries and arterioles. Repeated exposure to this stimulus leads to adaptive widening of resistance vessels and improved vasodilation capacity. The endothelium plays a key role: vasodilatory factors such as nitric oxide (NO) and prostacyclin are released in response to exercise, promoting vessel relaxation [14]. Endurance training increases endothelial cell proliferation, inhibits their apoptosis, and mobilizes circulating endothelial progenitor cells – all supporting endothelial repair and function. As a result, vessel distensibility and responsiveness to vasodilatory stimuli improve. Regular training promotes angiogenesis in skeletal and cardiac muscle, translating to better blood supply to active tissues and more efficient removal of metabolic byproducts [14, 15].

A significant long-term effect of running is the increase in the body's aerobic capacity, measured as maximal oxygen uptake (VO_2max). The largest gains in VO_2max are seen relatively quickly in the initial training period, after which progress gradually slows and reaches a plateau as individual potential is approached [12]. This phenomenon occurs due to central (cardiovascular) and peripheral (metabolic) adaptations [16]. Factors contributing to increased aerobic capacity include increased maximal cardiac output, blood plasma volume, and erythrocyte count, improved muscle perfusion (denser capillary network), and increased number and efficiency of mitochondria in muscles. Moreover, there is enhanced activation of oxidative enzymes and improved ability of muscles to use fats and carbohydrates as oxidative fuel. Overall, these peripheral adaptations result in an enhanced ability of working muscles to uptake and use oxygen, which, along with greater oxygen delivery via increased cardiac output and blood volume, raises VO_2max.

One of the most recognizable adaptations in long-distance runners is a decrease in resting heart rate due to regular training. Resting HR in trained runners is, on average, about 15 beats/min lower than in untrained individuals [12]. During submaximal exercise, trained individuals also reach lower heart rate values than untrained people at the same external load. Maximal heart rate usually does not change significantly with training (as it is largely determined by age and individual characteristics), but the rate of heart rate recovery after exercise improves substantially. In other words, a runner's heart beats more slowly at rest and works more slowly at a given submaximal workload, and after exercise, it returns to baseline values more quickly, reflecting an efficient adaptation of the cardiovascular system to regular activity.

Epidemiological statistics confirm that regular runners are less likely to develop hypertension, less likely to suffer heart attacks and strokes, and have lower cardiovascular mortality compared to inactive individuals [7]. The aforementioned changes in the circulatory system counteract the pathological processes leading to cardiovascular disease. However, the beneficial adaptations induced by running training last only as long as one continues regular running – they gradually reverse after training cessation (detraining). It is also worth noting that very intensive, long-term training can lead to certain adverse changes in the heart. Cases of myocardial fibrosis, atrial enlargement, and increased risk of arrhythmias (e.g., atrial fibrillation) have been reported in older long-distance runners. In rare situations, excessive enlargement of the right ventricle and impaired function have been observed – a phenomenon referred to as the exercise-induced cardiac remodeling syndrome [19, 20, 21].

3.2 Musculoskeletal System

During running, numerous muscle groups throughout the body are activated simultaneously – the body must maintain proper posture, absorb the impact of the feet on the ground, and ensure oxygen delivery to the working muscles. Local adaptation in muscle fibers includes, among other things, an increase in the number and volume of mitochondria and an increase in capillary density within the muscles. These changes increase the ability of muscles to transport and efficiently use oxygen in the energy production process. Changes in oxidative enzyme activity and increased levels of mitochondrial biogenesis markers (e.g., the coactivator PGC-1α) appear after just a few weeks of endurance training. These adaptations delay the onset of muscle fatigue during prolonged aerobic exercise [16]. A runner's muscles also show an increased ability to burn fat as an energy source and store more glycogen as an energy reserve. As a result of regular training, key endurance performance parameters improve – aerobic capacity (VO_2max) and lactate threshold. The increase in VO_2max results from the combined improvement in the capacity of the heart, circulatory system, and muscular adaptations, whereas raising the lactate threshold means that a runner's muscles can work aerobically for longer at higher exercise intensities before lactate begins to accumulate [16].

Regular running training also affects muscle fiber composition. Changes have been noted in the proportions of fiber types – running primarily engages type I slow-twitch fibers and type IIa fast-twitch fibers with intermediate properties. Under prolonged endurance training, the fastest anaerobic type IIx fibers can transform into type IIa fibers with greater oxidative capacity [22, 23, 24]. Simultaneously, adaptations in the nervous system improve neuromuscular coordination and movement economy – motor units are recruited more efficiently during running, which translates to better utilization of the muscles' potential. Despite improvements in endurance and functional strength, running training does not cause significant muscle hypertrophy – skeletal muscle growth in runners is small compared to the effects of strength training. Muscular adaptations, therefore, promote increased work efficiency and fatigue resistance at the expense of large gains in muscle mass and maximal strength [22]. In beginners, some increase in muscle strength and mass (especially in the lower limbs, e.g., the quadriceps) may occur due to running, usually in the initial phase of training or when additional stimuli such as hill running are used. However, with further specialization in endurance, increasing muscle mass is not a priority and proceeds to a lesser extent.

Running also has a significant influence on the skeletal system. Repetitive mechanical loads with each step stimulate bone remodeling and an increase in bone mineral density. Regular running training supports the maintenance or even increase of bone mineral density, particularly in the areas subjected to the highest loads – in the bones of the lower limbs, around the hips, and the spine [25]. Physical activity stimulates osteoblast activity and bone remodeling processes, which increases bone strength. Therefore, running can be considered an important element in the prevention of osteoporosis – regularly running individuals may have a lower risk of osteoporotic fractures at older age. Importantly, current research indicates that moderate recreational running does not increase the risk of developing osteoarthritis – on the contrary, it may reduce it compared to inactivity [27]. The reason for this effect may be the strengthening of periarticular structures and improved nutrition of articular cartilage under training. It has been observed that running can lead to thickening of joint cartilage and increased glycosaminoglycan content, which potentially protects the joints from degenerative changes [27].

Long-term running training also stimulates collagen synthesis – systematic loading causes the tendons of long-distance runners to become stiffer (higher Young's modulus), which allows them to store more elastic energy during each step and release it more effectively during the push-off phase. Joint ligaments also adapt to repetitive loads by structural strengthening [29]. Of course, one should not forget the potential negative consequences of excessive or improper running training. Too large a training volume or rapid increase in training intensity can exceed the musculoskeletal system's adaptive capacity. As a result, overload injuries may occur – microinjuries in bone structure (e.g., trabecular microfractures) leading to so-called stress fractures, especially if the body does not have sufficient time for recovery or lacks proper nutritional support. In summary, long-term running generally brings benefits to the skeletal system, but disrupting the balance between training, recovery, and nutrition can increase the risk of overload injuries.

4. Discussion

The presented data confirm that regular running induces multifaceted beneficial physiological adaptations, translating to improved health status and reduced risk of many chronic diseases. These adaptations concern primarily the circulatory and musculoskeletal systems.

In the cardiovascular system, the key effect of long-term running training is the improvement of the heart's efficiency and economy. Increased stroke volume and cardiac output, combined with reduced contraction frequency, result in a better supply of blood and oxygen to the body with a lower energetic "cost" for the heart muscle. The reduction of resting heart rate and blood pressure in trained individuals is an important cardioprotective factor – it helps prevent hypertension and pathological heart hypertrophy [6]. Moreover, improved endothelial function and increased coronary reserve protect against the development of ischemic heart disease [14]. All of this means that people who run are less likely to suffer a heart attack, stroke, or heart failure compared to inactive individuals [7]. In the context of primary and secondary prevention of cardiovascular diseases, running is therefore a recommended form of physical activity – this is reflected in cardiology guidelines and WHO recommendations, which suggest undertaking at least 150 minutes of moderate aerobic activity per week (or 75 minutes of vigorous activity). It is worth noting that running is an activity of relatively high intensity, so in the general population, it is recommended that beginners start with moderate jogging and gradually increase training loads as their bodies adapt.

In the musculoskeletal system, adaptations induced by running translate not only into improved physical endurance but also into the prevention of musculoskeletal disorders. Running provides stimuli that favor maintaining bone mass. Regularly running individuals have higher bone mineral density compared to inactive people, which serves as protection against osteoporosis. It should also be emphasized that controlled, recreational running (of moderate intensity and volume) can be safe for joints and even support their nutrition and function. Of course, injury prevention is key: properly chosen running shoes, varying routes and surfaces, regular exercises to strengthen the muscles stabilizing the joints, as well as proper recovery (stretching, rest) – all these factors allow one to enjoy running for many years without injury.

It is worth noting that extremely large training loads (e.g., ultramarathons, very high weekly mileage in the hundreds of kilometers) can potentially lead to overload of the musculoskeletal system and the heart. However, in the context of the general population, a much bigger health problem is a lack of exercise rather than "too much" exercise. The health message is therefore clear – for the vast majority of people, regular running in reasonable doses brings enormous benefits that far outweigh the potential risks.

5. Conclusions

Regular running induces a series of beneficial physiological adaptations encompassing the cardiovascular and musculoskeletal systems:

- **Cardiovascular system:** Running training leads to lower resting heart rate and blood pressure, increased stroke volume, and physiological remodeling of the heart (eccentric hypertrophy). Endothelial function and vascular compliance improve; protective HDL cholesterol increases, and atherogenic lipid levels decrease [6]. These adaptations translate into reduced risk of hypertension, atherosclerosis, and heart disease in people who run regularly [7].
- **Musculoskeletal system:** Running increases the oxidative capacity of muscles through enhanced mitochondrial biogenesis and angiogenesis, which delays fatigue and boosts endurance. Bones are strengthened due to repetitive mechanical loads – bone mineral density and bone formation activity increase,

contributing to osteoporosis prevention [24]. Moderate recreational running does not accelerate joint degeneration; on the contrary, it is associated with a lower risk of hip and knee osteoarthritis compared to inactivity. Running training also strengthens the muscles and tendons, stabilizing the joints, improving the overall function of the musculoskeletal system [30].

Regular running is an effective, inexpensive, and widely accessible “polypill” for health – it positively affects many physiological systems and processes simultaneously. Long-term running training strengthens the heart and blood vessels, muscles and bones, and improves metabolism, which together enhance health and quality of life. The results of this literature review strongly support including running (or similar endurance activity) in a daily routine as one of the pillars of a healthy lifestyle.

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