SECTION – FUNDAMETAL AND APPLIED KINESIOLOGY

(1.1) DOI: 10.5604/01.3001.0014.7767

INFLUENCE OF STRENGTH TRAINING ON SELECTED SYSTEMS OF THE HUMAN BODY

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

Keywords: strength training, resistance training, hypertrophy, strength training adaptations, neuromuscular adaptations, bone mineral density, cross section area, rate of force development, self-esteem, female resistance training, satellite cell strength training, urine loss resistance training, urinary incontinence, stress incontinence

Abstract:

Research aim: The objective of research was to present the influence of strength training on selected systems of human organs on the basis of available literature on the subject.

Methodology: A review was conducted of international literature based on analysis of selected articles available at Google Scholar, PubMed, SciCentral.

Results: Changes in the human body as a result of both strength exercises and training were demonstrated based on analysis of the available literature.

Summary: The results and the rate of benefiting from the practive of strength disciplines largely depend on gender, genetic characteristics, age, training history, health status, diet, lifestyle, current physical activity and stress levels.

Introduction

Strength training is a method of sports training that consists in increasing strength and muscle mass by developing the ability to counteract external forces with the use of free weights, machines or one's own body mass. Strength training sessions should be composed in such a way as to impose more and more external resistance and thus, stimulate further development of muscle strength [1]. Cultural and civilisation development has made modern people more and more aware of the significant impact of physical activity on health and everyday functioning. As a result of technological progress, it seems intentional to indicate various forms of movement as a way of counteracting civilisation diseases.

One of these forms is strength training, which affects many systems and organs of the human body. Strength exercises, in addition to muscle strength, also build endurance. By creating muscle mass and increasing its volume, it becomes possible to develop a healthy-looking, proportional, desired physique. Strength training provides a number of health benefits: it nourishes the joints, strengthens the ligaments and other periarticular elements, while affecting the harmonious development of physique. These exercises should be based on appropriate systems and professional training programmes [2].

Bodybuilding and strength sports are by no means a modern man's invention. The beginnings of this sport discipline date back many thousands of years. The authors of many historical sources state that people showed great interest and fascination with physical activity already in the times of Ancient Greece. An athletic, muscular bodyshape has become a lifestyle as well as an educational goal. Impressive physical fitness and muscle strength testified to the health of the body and mind. Ancient artists created sculptures of their gods in the image of muscular figures, with perfect body proportions, from which paintings were later drawn by artists in the Renaissance [3].

There are records documenting strength training with increasing loads, as the Greek wrestler Milo of Croton (540-526 BC), who was a 5-time Olympic winner, prepared for the competition by carrying a young bull each day from the time of its birth until the animal was 4 years old. Historically, the first "contract" bodybuilder was Eugen Sandow, who lived in the years 1867-1925. He is considered the person who initiated a new sport discipline, and his innovation consisted in public demonstrations of his developed muscles, as well as performances based on lifting "impressive" weights, often in the accompaniment of music. However, the authority of Eugen Sandow brought the most benefits to the physical activity of the mid-19th century society, which was then sedentary due to civilisation progress. Thanks to advanced physical strength and awe-inspiring musculature, the positive influence of physical activity on the human body began to be investigated and better understood. It was then that the devices used for maintaining well-being, dumbbells, and later, also more complex machines for strength exercises, saw the light of day. It has become obvious that people who want to increase their muscular strength and physical attractiveness will reach for these items. Obesity was avoided and an athletic figure was sought [4].

In the United States, in 1894, the world's first professional gym was opened thanks to Ludwig Durlacher, who is recognised as the first competent coach in Europe. After 1900, immigrants from Europe began to flow to the United States in the hope of finding a better job. They were very physically fit, their vigour impressive, being used to working hard to provide for themselves and their families. It became a pretext for the image of a strong, resourceful man, and the attributes of the classic concept of being masculine began to be cited. Soon, it was necessary to be physically healthy to fit into society, and the male body was the subject of social and economic discourses. Angelo Siciliano, better known as Charles Atlas, was a visiting card of those times. Inspired by the figure of Eugen Sandow, the bodybuilder became famous for publishing an exercise plan designed to improve both the body and mind within 12 lessons. The man placed great emphasis on acquiring the ability to take control of his own life in order to achieve strength, vitality and "true manhood". The series of exercises was comprehensively aimed at strengthening and building muscles; however, according to some sources, not all of the exercises proposed by Charles Atlas were actually created. The trainer was inspired by, among others, Indian exercises that control muscles, as well as Walter Camp's gymnastics [5]. In July 1950, Joe Weider, a Canadian columnist and bodybuilder coach predicted that the public would perceive physical and strength training as a metod for a long and happy life. He announced that an active lifestyle helps to reduce tension and stress, and the most important components of exercise with weights - a healthy diet, getting enough sleep, adequate rest and, above all, regular exercise - are the essence of a healthy lifestyle. Weider considered strength sports to be groundbreaking. Thanks to his publications in more than 30 journals, and many years of work, the public actually considered his predictions true and revolutionary. His name became synonymous with weight-training, the stereotypes of which he fought. Together with his brother Ben, in 1946, he created the IFBB (International Federation of Body Builders), which in 1955, organised the first world championship competition. To this day, the Weider brothers are considered the fathers of bodybuilding and training systems.

"Modern society is well-aware of the benefits of regular activity. The positive effects of strength training on mortality associated with civilisation diseases has been proved, these diseases being a significant threat to the population at productive age. The research focused on mortality as a result of cardiovascular events, diabetic complications, and cancer prophylaxis. Participation in strength training sessions is associated with reduced risk of developing type-2 diabetes in men aged 40-75, women aged 36-81, and the working population aged 30-64. It should be noted that these sessions did not include aerobic training. It is admitted that the training results would be even more favourable if they were combined with elements of aerobic exercise. However, compared to endurance exercise and other forms of physical activity, strength training is unique in terms of building muscle size, strength and mass, further minimising the risk of chronic disease and thus, reducing mortality. The World Health Organization recommends 2 Strength Promoting Exercise (SPE) sessions a week" [6].

The aim of this report is to present current knowledge about the influence of training and strength exercises on selected human organ systems, based on the analysis of available literature.

Research methodology

In the preparation of the work, international literature was mainly used, based on items published in PubMed, Google Scholar and SciCentral.

Discussion

Influence of strength training on the muscular system

Resistance training can be functionally defined as a progressive strain on the skeletal muscle, characterised by high muscle contraction force and anaerobic ATP re-synthesis. Long-term strength training results in many physiological adaptations that contribute to changes in muscle functioning. Resistance training triggers the process responsible for increasing the initial strength of muscle contraction, which is a combination of increased muscle activation and fibre hypertrophy [7]. The term muscle strength consists of many components, including: muscle cross-section (CSA), its architecture, tissue stiffness (muscles and fascia), recruitment of motor units and their synchronisation, as well as neuromuscular inhibition. Bilateral, concentric and resistance training can bring training effects due to good adaptation potential. In contrast, bodyweight, unilateral and kettlebell training may have some limitations in the development of maximal strength, although they are still very important pillars of strength training as a whole. Their high efficiency is noticeable due to various, demanding motor challenges that these exercises provide [8]. In order to determine the maximal strength of person performing strength training and to determine as well as visualise the effects of training, the one-repetition-maximum (1RM) measure is used. This unit is defined as the maximal weight a person can carry with 1 repetition of the exercise in full range of motion. It is a frequently used measure in the observation of training adaptations. In scientific literature, 1RM is also often used to measure strength as well as the effectiveness of a given training protocol. To define a person's maximal weight, it is common to carry out multiple attempts, gradually adding weights until the desired effect is achieved. However, this measure is then often biased due to skeletal muscle fatigue [9]. Increased muscle fibre size (hypertrophy) is the most noticeable effect of strength training [10]. Resistance training-dependent muscle hypertrophy occurs as a result of an increase and the amount of proteins in individual muscle fibres. Most of these fibres contain myofibrils with lots of proteins - myosin and actin. Therefore, hypertrophy is the result of biosynthesis and the formation of myofilaments with a simultaneous increase in the diameter of these fibres [7].

During this process, the contractile elements enlarge and the extracellular matrix expands to support growth. When a muscle is stimulated during resistance training, it perturbs the myofibrils. This series of events leads to an increase in the size and amount of contractile proteins - myosin and actin - and simultaneously, the total number of sarcomeres. This, in turn, increases the diameter of the individual fibres, leading to an increase in the cross-sectional size of a given muscle or muscle group. Colloquially speaking, the muscle, while being "forced" to cope with greater loads to which it is exposed, adapts to the new situation. Nonetheless, the definition of muscle hypertrophy should not be confused with hyperplasia, in which the size of muscle fibres increases, but not their number [11]. Skeletal muscles show high plasticity in response to strength training. This is necessary due to the mechanical and metabolic demands that arise from resistance training. Moreover, subsequent strength training sessions weaken the effects of oxidative stress [12]. In addition, factors such as gender, genetics, actual and biological age, an individual's sports history, health status, diet and supplementation, lifestyle, current physical activity level and stress factors have significant impact on the results of resistance training [13]. Mechanical muscle tension is an important stress factor accompanying strength exertion. All exercises produce tension in the muscle that is activated. Tension resulting from resistance training may disturb the homeostasis of the muscle, causing intracellular responses [14]. Muscle contractions also disturb the integrity of the sarcolemma (the lipid layer surrounding the muscle cell), which stimulates the concentration of membrane phosphatidic acid (PA), leading to activation of signalling pathways responsible for stimulating the process of hypertrophy [15]. Metabolic stress, apart from that mechanical, may also contribute to adaptation in the muscle [16]. The high rate of ATP exploitation during muscle work, and the resulting accumulation of AMP, the release of calcium cations from the sarcoplasmic reticulum and local muscle hypoxia in exercised muscles, can stimulate energy-regulating signalling pathways during resistance exercises [17].

Metabolic stress increases in an intensity-dependent manner during strength exercises. High metabolic stress, along with high accompanying mechanical stress, is believed to be achieved with a hypertrophy-oriented strength exercise protocol of approximately 6-12 repetitions per set, with each set performed up to muscle refusal, with relatively short intervals for rest between sets [18]. The skeletal muscles are perfectly able to adapt to contractile activity.

Physiological stress induced by strength exercise disrupts cellular homeostasis. As a result of chronic overload, these cells can adapt by changing cellular functions - it is necessary to return to homeostasis both during and after training. This ultimately generates functional adaptations in the muscle tissue [19]. Vigorous strength training, that is, one in which the trainee carries out a relatively large series of exercises with a high load and short rest intervals between sets, can result in an acute loss of ATP, phosphocreatine (PCr) or glycogen storage. However, it may additionally induce a high concentration of lactate, which will then cause a large proportion of anaerobic glycolysis in energy production. The consequence of the deficiency or depletion of glycogen stores may be post-training muscle fatigue [20]. Another effect of regular, long-term resistance training is an increase in the activity of anaerobic enzymes such as creatine phosphokinase, myokinase and phosphofructokinase. At a later stage of training, the activity of phosphocreatine and glycogen also experiences an increase [21]. The striated tissue of the muscle is the main one responsible for the disposal of glucose. It captures nearly 80% of glucose with insulin in a fed state. Glucose uptake increases significantly in muscles under stress during resistance exercise [22]. In many studies, it has been suggested that chronic strength training is effective in improving insulin sensitivity when exercise intensity exceeds 50% of 1RM. Satellite cells, which are silenced precursor structures located just below the basal lamina but outside the sarcolemma, play an important role in the process of hypertrophy [23]. When activated, these cells nourish existing muscle cells or are able to create new myofibrils, providing necessary precursors to repair those existing or to grow new muscle cells [24]. Furthermore, increased muscle activity during exercise may be responsible for the proliferation of satellite cells. The number of nuclei is a determinant of the rate of protein synthesis by providing the DNA necessary for gene transcription [25]. There is a theory insinuating that satellite cells play a key role in muscle memory with regard to strength training by preventing muscle atrophy in thnon-training strength training. period. These structures initially make the nuclei enabled to the next muscle fibres during the training period in order to support hypertrophy, and then, during the non-training period, they prevent apoptosis in the cells. However, this theory has not yet been thoroughly investigated in humans [26].

Long-term, regular resistance training increases muscle size and strength in both sexes and ages. Nevertheless, training results largely depend on the specific characteristics of the individual. Adaptation within muscle tissue is very important to withstand the hardships of everyday life, while weak muscles can restrict functioning alike a disease. Muscle strength and mass are seen as an important factor in the body's performance. However, in the research by Ahtiainen and his team, it is shown that age and gender do not have spectacular impact on the initiation of the hypertrophy process [7]. On the other hand, Konopka et al. note that in women and the elderly, hypertrophy after years of systematic strength training remains relatively low compared to young men. It should be added that hypertrophy induced by weight training is strictly dependent on the training programme [27]. "A decline in muscle mass leads to a decline in metabolic rate, eventually leading to an increase in fat mass. These harmful changes are associated with unfavourable metabolic processes and additional pathological processes, especially in old age" [28]. In contrast, long-term strength exercise is abundant in benefits concerning fat mass reduction while increasing lean body mass, resulting in an increase in metabolic rate [29]. Beneficial changes in the skeletal muscle can affect the ability of muscle tissue to produce power. An increase in muscle cross-section (CSA) has direct impact on overall muscle strength. The reason behind this phenomenon is that an increase in type-2 muscle fibres means an increase in total muscle strength [30]. A strong correlation has also been demonstrated between the increase in muscle cross-section area and the production of force by the muscle [31]. Narici et al. suggest that short-term strength training may increase the muscle-produced power by as much as 50-60% in non-training units [32].

An important determinant of muscle function that affects its strength is so-called muscle architecture, i.e. the structural arrangement of interdependent muscle fibres and connective tissues within it [33]. Another factor that may increase power flow is tissue stiffness, i.e. the relationship between the power delivered and the degree of stretching to which the tissue is subjected [34]. In addition, adaptations in the tendons and structures within the muscle (actin, myosin, titin, and connective tissue) may affect muscle strength [35]. The proteins included in the sarcomere as well as the connective tissue show an elastic effect. The production of muscle strength occurs in an environment that exhibits these characteristics, and it is a decisive factor in muscle performance during movement.

Muscle strength and power depend on the speed of contraction. By influencing the speed of contractile elements, it is possible to notice significant impact on the work and power of muscles [36]. Titin turns out to be an underappreciated protein that plays a role in generating and expressing power [37]. It is responsible for creating passive tension in the sarcomere in which it is located [38]. It should also be noted that an increased amount of sarcoplasmic calcium may contribute to an increase in titin stiffness, and thus, an increase in the stiffness of the entire sarcomere [39]. Accordingly, changes in muscle strength and power transmission may be at least partially dependent on changes in the stiffness of the tissues within the muscle as well as the structures surrounding it [40]. Cameron et al., analysing the impact of load level during the strength training of young men showed that an increase in type-1 and -2 fibres occurred regardless of whether they trained in accordance with the load training protocol totalling 30% 1RM or with a load of 80% 1RM [41]. By contrast, in an investigation conducted by Julius Fink et al., the effect of strength training on hypertrophy and the development of muscle strength was show. This was done using 3 training protocols for this purpose:

high load of 80% 1RM (8-12 repetitions), low loads representing 30% 1RM (30-40 repetitions) and a non-linear blended training protocol, in which participants changed the size of heavy loads to light loads every 2 weeks. The exercise implemented for the research guarantees the control of the biceps muscle of the shoulder - so-called Preacher curl exercise. In the experiment, such factors were investigated as rate of force development (RFD), maximal voluntary contraction (MVC) and cross section area (CSA). The training lasted 8 weeks and was carried out among 21 young males. The results of the experiment included an increase in CSA form each group, regardless of the load degree during training. Based on the results, it may be concluded that the occurrence of hypertrophy is not dependent on the burden.

Muscle strength, on the other hand, increased significantly only in the group of exercises with high loads, thus, its increase is closely linked with high loads used during strength training. However, this situation was different in non-linear training, where periods of exercise with low loads did not stimulate the phenomenon of hypertrophy. This incident is probably related to the difficulty of adapting the neuromuscular path due to low loads. It is also of significance that the 8-week period of training was likely not sufficient to demonstrate its benefits [42].

Nevertheless, Steven J. Fleck has demonstrated the benefits of non-linear force efforts. These include reduction of body mass and body fat, as well as an increase in endurance. Importantly, in his research, he also proved positive effects on muscle strength and power [43]. In the study [44], various variables of resistance training were examined, such as: interval duration between sets, load level, selection of specific exercises, number of series performed, frequency of performing training session, which have been thoroughly researched to maximise hypotrophic response to the applied training. Based on the analysis of this evidence, it can be indicated that the adaptation to various strength training protocols is similar [44]. Classic strength training is based on external loads that usually vary between 1RM-10RM. and the number of repetitions is between 4 and 12 [45]. Adaptation to strength training is evident between 8 and 12 exercise weeks [46]. However, in some sources, it is indicated that the increase in muscle strength and cross-section area may occur as early as between the 2nd and 4th weeks of exercise. This, however, may be induced by muscle edema at the initial phase of training [47].

Training intensity plays a key role in the adaptation process to resistance efforts. In fact, the most recommended loads are heavy in this type of training. However, training with a slightly lower external load, but working until the muscle is tired and not working, can compensate for the lower load and lead to the same results of muscle growth and strength as training with high loads [48]. The authors of this study demonstrated a close relationship between time intervals and series of exercises, as well as long-term adaptation to training programmes, such as muscle strength, endurance and body hypertrophy. Intervals for rest between sets lasting from 3 to 5 minutes contribute to an increase in total muscle strength [49]. The reason why longer intervals better support the process of increasing muscle mass and strength can be explained by the fact that longer rest regenerates the body and allows for better performance during exercise and achieving better training and sports results [50].

In the somewhat earlier research conducted by Ahtiainen et al., it was shown that the length of regeneration between series was important in the case of hormonal or neuro-muscular response, or the long-term effects of adaptation in the muscle tissue among the studied men practicing recreational sports [51]. Comparing the muscle mass of bodybuilders training with moderate weights, thus, taking short intervals between series that produce a large amount of metabolic stress, and powerlifters who train with very intense loads, resting for a longer time, the conclusion arises that both these sports groups are characterised by impressive muscles. Therefore, it is difficult to unequivocally state which method is better for the fastest and most effective growth of muscle tissue [52]. Each strength training type causes some degree of damage to the stressed muscles depending on the intensity of the exercise and the individual characteristics of the person exercising. Typically, however, a training session produces mild damage and takes several days to fully recover [93]. Myofibril misalignment and Z-streaming are characteristic of resistance training, especially if it involves predominantly eccentric muscular actions. It has been suggested that, due to the specific neural response to eccentric contractions, as compared to concentric contractions, fewer motor units are involved for a given load. This would result in a greater strength demand for an active motor unit, thus, predisposing the involved muscle fibres to disturbances, especially post eccentric exercises, to which the exercising person is not adapted [54].

Strength exercise-induced disruptions in myofibrils can cause acute local inflammation, being a response to tissue damage, which should initiate muscle regeneration. The inflammatory response the movement of fluids, plasma proteins and leukocytes to the site of cell homeostasis disturbance, which is manifested by the onset of muscle pain, stiffness and swelling, as well as a temporary reduction in the ability to generate force in the muscles under stress [55]. The penetration of immune cells into damaged muscles begins within 2-3 days after damage. The inflammatory response removes damaged tissue and deals with the regeneration of damaged muscle fibres [56]. Subsequently, secondary inflammation involves monocyte infiltration in the damaged fibre to trigger a further phagocytic response. Ultimately repair and regeneration of muscle tissue occurs after exercise [57].

Influence of strength training on the nervous system

The nervous system has influence on strength exercises. The specific neuromuscular adaptations responsible for the increase in muscle strength are often distinguished as strictly nervous and morphological [58]. One of the major nervous adaptations to strength training is the increased ability to maximally stimulate the motor neurons, which may be a secondary adaptation to, e.g. decreased nervous inhibition [59]. Neuromuscular inhibition refers to the reduction in nerve conduction of a given muscle group during muscle work, which may adversely affect the power of strength through nerve feedback from muscle and joint receptors [34].

In research, it has been shown that resistance training increases the neural pathway from the spine level, thus, reducing the inhibition of neuromuscular conduction [61]. In a study by Balshaw et al., comparing the impact of 4-year and 12-week strength training aimed at neuromuscular activation, similar agonist activation was demonstrated in both cases, which means that this adaptation can be maximised in the first months of training. However, coordination between muscles was progressively worse [62]. Henneman et al. indicate that motor units are activated from the smallest to the greatest [63]. Therefore, the involvement of motor units depends on the amount of power required to fulfil a given objective. For example, smaller motor units, which contain mostly slow twitch type-1 fibres, will be activated when less power is required for a muscle group to complete a given task. Thus, larger motor units, which are mostly composed of type-2a or -2x fast twitch fibres, can only be recruited when high force values are required [64]. The type and intensity of an activity is closely related to which motor units are involved and how they adapt. Typically, motor units containing type-2 fibres are activated when motor units containing type-1 fibres become fatigued, and additional power is required to sustain the activity. Weightlifters practice training where type-2 motor units are engaged. On the basis of order in participation, it can be suspected that training with weights allows the recruitment of motor units containing type-1 and -2 muscle fibres, allowing them to be trained [65]. Once specific motor units have been recruited, the frequency of motor neuron discharges to the muscle fibres can modify the properties of producing muscle strength. In the research by Enok RM and his team, it has been shown that the amount of strength can increase by as much as 300-1,500%, in direct proportion to the increase in the frequency of impulses sent by moto-neurons to the muscle fibres [66]. Neuro-muscular adaptation, as a result of strength training, stimulates the increase in strength and power, thereby increasing the cross-section area of the muscle tissue, and causing compactness in connective tissues. The phenomenon of adaptation consists mainly in the activation of the neuromuscular system and the acquisition of skills by the nervous system to synchronise motor units as efficiently as possible, and to recruit them. The nervous component is one of the most important factors in the process of strength-increasing training, as shown by the phenomenon in which one limb is trained while the other is not subjected to strain. Then, there is an increase in strength of the non-exercised limb, despite the lack of changes in muscle cross-section [67]. This phenomenon, called cross-transfer or contra-lateral training effect, results in improvement concerning the functioning of the efferent nerve pathways in the untrained limb [68]. While evidence allows to strongly suggest changes occurring in muscle strength with strength training, the literature on changes in motor unit synchronisation following resistance training contains conflicting views. Some authors report that 6 weeks of strength training increases the synchronisation of motor units, which contributes to increased power generation by the muscle. In practice, it seems that strength training sessions can cause motor unit synchronisation improvement.

Influence of hormones on skeletal muscles during strength training

Hormones such as testosterone, the growth hormone (GH), insulin, cortisol and the insulin-like growth factor (IGF-I) can significantly affect muscle mass. Strength training may induce a temporary, post-training increase in the concentration of some hormones [69]. These endocrine responses can be triggered by the overall regulation of the body's metabolism to ensure access of glucose and free fatty acids muscles at work [70]. Hormones may induce muscle cell responses through receptors in reply to elevated levels of circulating hormones. [71]. However, physiological fluctuations in hormones seem to have only a protective role, not being a stimulus in regulating muscle size [72]. The authors of the research report that changes in the concentration of testosterone and cortisol may, in some cases, change under the influence of training loads. Therefore, it has direct impact on the regeneration and metabolic stress of athletes [73]. The anabolic effects of IGF-I in the skeletal muscle are clearly defined, however, this factor only partially contributes to hypotrophic response. On the other hand, local expression of growth factors such as IGF-I in the muscles under load, in response to strength exercise, is likely to play a significant role in the process of hypertrophy. IGF-I induces the proliferation of satellite cells and also increases the accumulation of contractile proteins in myofibrils by activating IGF-I receptors in the plasma membrane [23]. Compared to IGF-I, myostatin is the major negative regulator of skeletal muscle growth. Myostatin is produced and secreted by contractile muscle fibres, increasing autocrine, paracrine and endocrine responses. Myostatin is responsible for the inhibition of satellite cell activation, suppression of myogenic regulatory expression factors, while promoting proteolysis [17].

Influence of strength training on the cardiovascular system

The benefits of strength training on changes in strength maintenance and muscle volume are well-understood. However, the role of strength training in altering cardiac metabolism is not well-defined. Most of the research on weight training has been focused on changes and adaptations in the size and strength of skeletal muscles, with few researchers studying effects on the cardiovascular system as a primary effect of training. However, some authors cite cardiometabolic outcomes as a secondary effect of strength training [74]. While the evidence allows to strongly suggest the effects of strength training on improving health, the effects of this type of training on the heart and risk factors for cardiac events are somewhat unclear. Meanwhile, there are authors who prove that a relatively short period of strength training can significantly reduce risk factors for heart disease, including glucose and insulin metabolism [75]. Saeidifard et al. conducted a review of the direct effect of resistance exercise and the reduction of heart disease risk factors in terms of the effect of training on mortality. After analysing all the research works on this subject, it was concluded that strength training used alone and in combination with endurance training reduces overall mortality and mortality associated with cardiac events, including coronary heart disease. Nonetheless, these data are insufficient [76]. In studies on the effects of 1-year strength training on the lipid profile and chylomicron concentration in older men, a significant decrease in LDL-transported cholesterol was noted compared to the active control group. During the 1-year experiment, the test group participated in 1 resistance training session per week, 1 hour a day. However, the experiment indicated no changes in fasting triglycerol and glucose, or in chylomicron concentration [77]. The authors of studies exploring cardiovascular adaptation to resistance training in older postmenopausal women also demonstrated a positive effect of strength exercise on the cardiovascular system. After 12 weeks of training, systolic blood pressure decreased significantly. Nonetheless, training did not affect diastolic blood pressure and heart rate in the study group [78]. Similar results were obtained by Otsuki T. et al. studying systolic blood pressure during low-intensity resistance exercises. Systolic blood pressure after the training session was lower compared to the control group [79]. However, resistance training has been found to have impact on heart rate variability (HRV). Using rigorous resistance exercise has shown that young healthy adults experience a greater reduction in parasympathetic heart modulation than with aerobic exercise, suggesting an increased risk of cardiovascular dysfunction following strength exercise. Regular strength training does not appear to affect resting HRV in healthy young adults, while it may improve parasympathetic modulation in middle-aged adults with autonomic dysfunction [80].

Influence of strength training on the skeleton

Mechanical forces acting on the bone turned out to be very important for a properly functioning skeleton. They come from 2 main sources: external gravity and internal loading, through the influence of muscle cramps. The action of these forces can be significantly reduced by a sedentary lifestyle, by prolonged immobilisation, disease, and also by reduced gravity in space flight. Reduced physical activity and infrequent muscle contractions cause muscle wasting as well as loss of bone density. There is a strong relationship between muscle and bone tissue. Muscles are the source of myokines which can stimulate both bone formation and bone degradation, while bones secrete factors such as osteocalcin, which has a direct effect on muscles. Defining the cellular and molecular mechanisms connecting muscle and bone is critical to develop therapeutic approaches to inhibit muscle and bone atrophy, and to prevent bone fractures [81]. Thus, bone tissue responds specifically to high-force mechanical loads. The size of the load is essential for the interaction of the musculoskeletal system. Strength exercises involving multiple bones, such as weight-bearing squats or the deadlift, are performed in bone-loading positions and require extensive muscle involvement in this process. These exercises can cause heavy loads in important areas such as: the spine or the hip joint. Nonetheless, in experiments examining the effect of resistance training on bone density in postmenopausal women with confirmed osteoporosis or osteopenia, not increase was demonstrated in the density of the femoral neck and lumbar spine bones among the study group. However, it should be noted that the test was not long enough to detect changes in bone mass. The too small number of cases must also be taken into account [82]. Other authors suggest that strength exercise is highly effective during space expeditions to prevent the decline of muscle and bone mass when exposed to prolonged microgravity [83]. Furthermore, it is stated that resistance exercise is one of the best ways to improve skeletal health [84]. High-intensity progressive resistance training has been established as an effective strategy in stimulating osteogenic response and maintaining bone mineral density in adults and the elderly [85]. However, evidence regarding the effect of high-intensity resistance training on bone density in postmenopausal women still remains controversial. Moreover, adaptive bone response to resistance exercise is often specific to the site under stress [86]. In an analysis of clinical trials with similar results, it was shown that strength exercise, high-intensity compounds were only effective in preventing postmenopausal mass bone loss in the lumbar spine [87]. Kemmler et al. demonstrated positive effects of exercise in reducing the risk of osteoporotic fractures of the hip and spine [88]. On the other hand, the previous experience of Milliken et al,. investigating the effects of resistance exercise on bone mineral density and bone formation in postmenopausal women, with and without hormone replacement therapy, indicated no positive or negative effects following strength training sessions [89]. It is also worth mentioning research regarding the effects of resistance training on bone mineral density in patients suffering from breast cancer. People who receive chemotherapy treatment lose bone density by an average of 2-8% compared to baseline. Combining pharmacological treatment of bone mass loss with strength training, where physical activity used as a method of treating reduced bone mass, seems to be a good solution, knowing that pharmacological treatment has many side effects. In current research, the positive effect of strength training has been documented in breast cancer sufferers during and after treatment compared to the non-exercise group, however, more cases are required to conclusively determine whether resistance training can be therapeutic in treating bone mineral density disorders among individuals diagnosed with breast cancer [90].

Influence of strength training on the urogenital system

The World Health Organization (WHO) and the International Society for Continuity (ICS) define urinary incontinence (UI) as the involuntary leakage of urine from the bladder, which is a hygienic and social problem. Estimates show that 5-69% of women experience at least 1 episode of incontinence or loss of urine within 12 months. Risk factors for the presence of UI vary. These include: age, pregnancy, number of natural births and diabetes. Significant (modifiable) risk factors are oestrogen substitution and abnormal (high) body mass [91]. In contrast, stress urinary incontinence is associated with leakage of urine when the intra-abdominal pressure is increased and the bladder is unable to resist this pressure. Such increased pressure occurs when lifting weights. Additionally, the intra-abdominal pressure increases in direct proportion to the size of the weight lifted. Women practicing powerlifting - which is a high-intensity strength discipline, consisting of lifting weights in a squat with a barbell, deadlift or bench press, often additionally wear abdominal belts, and hold their breath while lifting the barbell to stabilise the trunk and spine, and thus, also increasing intra-abdominal pressure to a greater extent. These situations put a great strain on the pelvic floor muscles. As it has been proven, an external weight of 2.5 kg significantly increases the pressure in the abdominal cavity, and yet women who practice powerlifting, lift much heavier weights [92]. An anonymous survey among young female powerlifters was conducted to investigate behaviours inducing incidents of stress urinary incontinence. The examined women did not have a history of stress urinary incontinence during everyday life or dysfunction of the pelvic floor muscles and the bladder. Analysis of the results showed the problem of stress urinary incontinence among women lifting weights. Among the 38 participants, as much as 74.5% admitted that they had experienced urine leakage during training in the past. The authors of the study indicate that urinary incontinence among women who perform powerlifting is a common problem, and wearing an abdominal belt while exercising may exacerbate this problem. Stress urinary incontinence may have additional consequences in the form of withdrawing from participation in training and competitions, which is conducive to the feeling of stress among training women [93].

Influence of strength training on psychological aspects and body perception of men and women at different ages

Body image perception is a multi-dimensional term, defined as the way a person thinks, acts and feels. Individuals with low self-esteem may perceive themselves as unattractive, too overweight, not muscular enough, or too thin and frail. As a result, these people are at risk of developing depression, stress, anxiety, symptoms of eating disorders, as well as muscle dysmorphia. According to the authors reviewing 11 studies on the impact of strength training on body image, in the majority of studies (8 out of 11), it has been suggested that resistance training may significantly improve many aspects comprising body image, including satisfaction with appearance, evaluation of appearance, and may also reduce experienced social anxiety. It seems that strength training can improve body image in adults, but there are no reports in the literature in which these considerations would be confirmed [94]. Based on previous studies, a close relationship between muscle strength in male students and the improvement of self-esteem has been show, as well as satisfaction with appearance. It is worth adding that analysing research, in which the relationship between maximal muscle strength (measured with the 1RM unit) and general self-esteem of students was explored, a significant correlation was demonstrated between muscle strength and body image. However, these correlations were statistically significant only for the male part of the respondents [95]. Men who do strength training are often dissatisfied with the appearance of their muscles.

Analysis of mental state regarding men practicing strength training demonstrated a greater tendency of athletes to show affective and antisocial disorders. Among the subjects, there were also mania or hypomania syndromes of unexplained aetiology concerning body shape [96]. Social expectations and standards regarding the ideal body composition of men and women have changed over the years. The authors of numerous studies have identified the ideal posture of men as strong, muscular and athletic. This may be the source of frequent muscle dysmorphia occurrence in bodybuilders, defined as the subjective belief that muscles and muscle strength are too small [97]. Based on studies concerning strength training in obese women and the influence of exercise on psychological aspects, a positive effect of training on exercise motivation itself, as well as positive body perception, was shown. On the other hand, it was difficult to motivate non-training, overweight women to exercise regularly [98].

Resistance training is an exercise variant through which young people can increase their self-esteem. A study was carried out on the basis of which 6-month strength training on the body image of overweight Australian, male youth was examined. During the experiment, large statistical differences were observed in the test group compared to the control with regard to self-esteem, self-confidence and positive body assessment [99]. Similar results were obtained by Goldfield et al. demonstrating the reducing effect of resistance training and combined training on depressive symptoms in the studied adolescents. The authors suggested that strength training may improve body image and mental health in overweight or obese adolescents. Strength training may be used in the future as an alternative method to endurance training in the fight against obesity and psychological problems of adolescents [100]. It is worth noting that regular aerobic training combined with moderate-intensity strength training brings positive psychological effects in people with HIV, regardless of disease stage and accompanying symptoms [101]. Physical activity has also been proven to positively influence physical and mental health in the elderly. Regular physical activity reduces the risk of depression symptoms, states of low mood or anxiety. A study was conducted among 358 seniors who completed questionnaires regarding time spent in a sedentary manner and strength exercises. The respondents were also asked about mental health, satisfaction with life, anxiety or depressive disorders. Based on analysis of the results, it was found that people who spend less time sitting, or less time sitting and additionally performing strength training, experience greater satisfaction with life and fewer symptoms of psychological disorders [102]. Based on the analysis of results obtained in other studies, the benefits of strength training have also been shown in elderly people. Compared to the control group, in addition to the physical benefits in the form of increased strength, the training participants also noted significant improvement in memory and a lower feeling of anxiety and stress, regular training and its duration especially increasing these benefits [103].

Conclusions

- Strength training has been present in culture and society from ancient times to present day.
- Adaptations to resistance training in the skeletal muscle are the most distinctive feature of training with external resistance. These adaptations are most precisely defined in the available literature.
- The nervous system is actively involved in the coordination of skeletal muscles during strength training.
- The endocrine system plays a significant role in enhancing hypotrophic response and other adaptations to resistance training.
- Not much research has been conducted regarding the effects of strength training on the cardiovascular system. In the results achieved to date, some adaptations to the vessels can be seen.
- Resistance training and increasing muscle mass have an effect on bone mineral density.
- Women who practice strength training are at an increased risk of stress incontinence episodes.
- Strength training can have a positive effect on body shape, but it can also affect the perception of one's appearance.

Summary

Much research has been conducted regarding the effects of strength training on the locomotor system, as well as nervous system that controls it. However, the exact mechanisms of how strength training affects individual structures in the human body are not yet known. The effects of strength training on other systems in the human body have not yet been defined in detail, and more research is required in order to identify what changes occur in the human body as a result of this type of training. Nonetheless, it is known that properly planned and performed resistance training initiates many health benefits for people of all ages, regardless of gender. It should be added that the results and pace of benefits acquired from strength sports training largely depend on gender, genetic characteristics, age, training history, health, diet, lifestyle, physical activity and level of stress.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee

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