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THE ROLE OF MOVEMENT IN INCREASING OF BONE DENSITY

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Abstract

*Aim.*The movement reported at microscopic level, but also at the human being, has an important rol in maintaining optimal quality of living matter.

It is, practically, the stimulus necessary for bone formation with effect on increasing bone density and hence, decrease the risk of fractures, especially in elderly people. Presence in human life of physical activity provides not only physical health, but also mental health, resulting in improved quality of life.

Purpose. The aim of this paper is to demonstrate the mechanisms involved in making motion, and identifying the role of movement in bone formation.

Objectives. Objectives are represented essentially by highlighting key anatomical and functional structures underlying motion and the mechanisms involved in bone formation.

Methods. The research method used was the study of theoretical documentation represented by specialized bibliography.

Conclusions. Anatomical and functional peculiarities of the main structures involved in movement - nervous system, muscular system, osteoarticular system - are essential for understanding the mechanisms underlying achievement of movement and the consequences of its lack, not only on these structures, but also on whole body. Muscle contraction by traction exercised on the bone, plays a role in triggering of the process of bone formation while the kinetic programs tailored clinical features of patients with osteoporosis or at risk for osteoporosis, may favorably influence their evolution.

Key words: osteoporosis, bone mass, piezoelectric effect, mechanical stress.

Introduction

It is a well-known fact that, since the beginning of time, man has earned his living through physical work. As time passes, due to the development of technology, physical labour was gradually replaced by various machines that took over some part of man's physical effort. In parallel, the development of science allowed the step by step outlining of the importance of movement, both for the physical and for the mental health of the human body. At the same time, adverse effects due to inactivity or prolonged immobilization have been shown on human health and development in general.

According to the "Declaration of consensus", developed at Turin in 1992, during the II "International Symposium on physical education, fitness and health", physical activity is defined as "*any movement performed using skeletal muscle which results in a substantial increase in energy consumption during rest*" (Roman, 2008:7).

The structures involved in achieving motion are complex, being mainly represented by bones, muscles and nerves. The mechanisms for adjusting to effort are based on the involvement of the cardiovascular system, respiratory system, nervous system, and also on a series of changes that occur at the level of the tissue metabolism. In order to determine the physiological changes for adapting to effort, the stimulus must have the ability to produce a stress on the structures of the body, a stress that will compulsorily result in a state of vitality, energy.

„An adequate physical capacity, by practicing

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regular physical activity, translates into increased physical performance, self-confidence and a physical and psychological independence, also contributing to the perceived quality of life." (Roman et al., 2008:32).

On the other hand, prolonged immobilization causes changes at various levels of the body.

For example, at the *cardiovascular* level we see a number of changes emerging due to a disruption in the adaptive mechanisms that the body has created as a result of adopting vertical position. Thus, under the conditions of bed immobilization, the loss or lack of "gravitational stress" causes a disruption or suppression of these adaptive mechanisms, resulting in the consequences:

- the information from pressoreceptors is inadequate, causing the excitation of renin-angiotensin-aldosterone axis with increased excretion of water and electrolytes, resulting in hypovolemia;
- the venous stasis together with hypovolemia and the cardiac inadequacy to effort, determine a decreased systolic flow. In the case of physical activity, the increase of cardiac output will be caused by the rise in heart rate with increased oxygen consumption in the myocardium;
- the decreased venous return associated with haemoconcentration (due to increased excretion of water and electrolytes) determines favourable conditions for the occurrence of venous thrombosis;
- hypovolemia and the alteration of the pressoreceptor mechanisms result in orthostatic hypotension at the time of vertical lifting, with decreased cerebral perfusion. In the elderly, due to cerebral arteriosclerosis, the installation of hypotension can cause transient ischemic attacks.

Among the changes in muscle metabolism we meet: hypo / muscle atrophy, decreased muscle strength and endurance, decreased content of macroergic and myoglobin molecules, a negative balance of sodium (Na) and potassium (K) ions, decreased oxygen transport capacity (O2) (due to anaemia, decreased cardiac output, and so on) and of its quantity, and due to impairment of respiratory mechanics, muscular hypotonia occurs. Thus, the muscle, when resuming work, will have a low buffering capacity of acids produced during exercise and an affected local oxidative capacity.

At the level of the locomotor system, contractions occur and afterwards retractures, with increased tensile resistance. The strong influence exerted by movement on the biological processes of the bone has also been prooved. Thus, movement, shaft or lateral pressures are bone formation stimulating factors , following bone collagen fibres slipping from each other, leading to the appearance of a difference in electrical potential, a process that is based on the so-called "piezoelectric effect" (Sbenghe, 2005:34), the cause thus being a mechanical one, while the effect is electric.

Other changes in the locomotor system are represented by decreased elasticity of soft tissues due to the alteration of collagen secretion (which seems to decrease by almost half if the segment is immobilized), joint stiffness, synovial inflammation, erosions, cysts, fibrous organization which leads therefore to the installing of stiffness, a number of adhesions at capsuloligamentar , musculo-muscular and musculo-skeletal level; venous stasis accompanied by oedema and fibrous organization; muscle heterotopic ossification (met in immobilizations caused by central nervous system disorders) or algoneurodistrophy of the paretic limbs, especially on the upper limb.

In its turn, the respiratory system suffers changes which include: decreased functional capacity of the lung by 5-7% each week. On the other hand, the supine position causes the limiting of chest expansion in the posterior and medial areas, ventilation being accomplished mainly on account of ventral and external areas. Thus transient atelectatic areas appear, but they may influence lung function through their stretching. To these we also add a shortage of bronchial drainage. Lung circulation is affected, leading to pulmonary stasis manifested especially in the posterior and basal areas. All these favour, in their turn, lung infections and lung micro embolisms.

In these persons we often meet the installation of depression, and also a loss of sensory-motor engrams following prolonged immobilization. Studies show that due to lack of exercise, especially in athletes when they stop training, the body will produce a series of relatively fast changes, which are, to a certain point, reversible "*with the decrease to 40% of mitochondrial cytochrome oxidase in approximately 2 weeks and maintenance of low levels after 2-6 weeks, and at the same time it cause a decrease in VO2 by maximum 5% after in about 6 weeks.* "(Tache, Staicu, 2010).

Through information gathered from specialty studies, we appreciate the overwhelming importance of movement on bone formation and, not least, on the quality of human life.

We believe that the approach to movement in terms of anatomical and functional structures involved, and also of its positive effects on the body, is a matter that needs to be investigated in detail. The purpose of this paper is to demonstrate the mechanisms involved in achieving movement, and to identify the role of movement in the formation of bone.

The objectives can be essentially grouped as follows:

- General objectives - represented by highlighting main anatomical and functional structures underlying movement;
- Theoretical objectives -represented by the study and interpretation of specialized literature to support the scientific approach of the topic, but also by the emphasizing of the theoretical aspects supporting the practical application;

- Practical-applicative objectives - represented by the highlighting of the role of movement in the formation of bone.

Getting to know the anatomical and functional peculiarities of the main structures involved in movement - nervous system, muscular system and osteoarticular system - is essential for understanding the mechanisms underlying the achievement of movement, but also of the consequences of its lack not only on these structures, but also on the entire body.

As a hypothesis, we propose the following:

1. If we highlight the anatomical and functional peculiarities of structures involved in movement, we can more accurately understand how it is done.
2. The understanding of the way in which movement is made will lead to understanding the effects of movement on the body and primarily on bone.
3. By knowing the effect of movement on bone, we will have a more accurate perception about the involvement of movement in the formation of bone.

Movement is undoubtedly the mode of existence of living matter, essentially one of the fundamental manifestations of life.

Not only a sedentary lifestyle, but also the transition to bipedal posture was the one that led, as noted above, to the occurrence of changes in the body. In an article published in the October 2011 number 6 issue of the journal PLOS ONE, Ohio, USA by Meghan M. Cotter and colleagues, regarding human progress and osteoporosis, it is shown that a series of adaptations following the bipedal posture have occurred at the level of human vertebral bodies, which resulted in a lower strength of the vertebral body compared to those of monkeys: the distribution and orientation of bone bays have similarities, despite the peculiarities of human and ape locomotion; it also seems that spine load and kinematics are similar in the 2 studied groups. Instead, human vertebrae are larger in size, but the amount of trabecular bone is reduced, the human vertebra is more porous and the cortical thinner.

The fact is that the incidence of vertebral body fractures due to osteoporosis is quite high in humans, while in monkeys they are missing even though they have a high degree of osteopenia. It seems that the thinning of the vertebral body cortical associated with the prolonged flexed position adopted by man very often during daily life, plays an important role in vertebral body fractures.

About the effects of the prolonged immobilization on bone, specialists in the field have established that they exist and that, often, due to the arising complications, mainly represented by fractures, they have a bad influence on individual lives. Thus, immobilization may lead to decreased bone mass and osteoporosis. Osteoporosis is the most common bone disease characterized by decreased bone mass, changes in bone architecture, elements that lead to a decrease in its resistance and an increased risk of fracture. The increased incidence of osteoporosis as a disease, especially the appearance of its complications mainly represented by fractures, caused a continuous increase in expenditures for the treatment of patients suffering from this condition.

A study conducted by the U.S. National Institutes of Health, published in October 2011 in the journal Archives of Internal Medicine, showed that women who suffer hip fractures between the ages of 65-69 years have a five times greater risk of dying next year because of postoperative complications as compared to women from the same age group who did not suffer such fractures. "*For patients who underwent hip fracture and died in the first year after the accident, more than half died within three months after the fracture and almost three quarters in the first six months*", said the researchers.

In addition to bone formation, exercise plays a role in maintaining a normal body weight, which in turn influences the quantity of bone mass. Until recently it was thought that a heavier weight than normal would reduce the risk of osteoporosis, due to the high mechanical load exerted on the bone. A study published in the Journal of the Clinical Endocrinology and Metabolism by Zhao and co. from the University of Missouri-Kansas in 2007, shows that an increase in weight and therefore increased mechanical loading of the bone is favourable only until a normalization of individual weight (if it is reduced). As we move away from normal values to some increasingly larger ones, it was found,however, that is caused a decrease in bone mass.

Essay content

Several structures are involved in achieving movement, mainly represented by the nervous system, muscular system and the skeletal one.

At the level of the nervous system, the achievement of a voluntary movement requires the intervention of three types of systems :

1. The sensory system - represented by cortical somatosensory areas of the parietal lobe, which integrate proprioceptive, exteroceptive (mainly tactile), vestibular, visual, auditory afferents;
2. The motor system - represented by motor cortical areas that give the motor command, thus initiating and controlling the response. They are represented by: the main motor area (area 4 Brodmann), the supplementary motor area, the premotor area, frontal optical area;
3. The regulator system, represented by the bone marrow through the loop range and extrapyramidal structures involved in providing the tonic postural and balance fund, and also the automatic movements necessary to conduct the voluntary act.

Skeletal muscles are the actual organ of the locomotor system, as they are causing the human body movements due to their property to contract. In addition to the common structural elements found in a cell, the muscle fibre also contains a few particular types of proteins represented by: contractile proteins (actin and myosin), regulatory proteins (troponin and tropomyosin) and structural proteins (for example conectine).

The electric impulse that reached the sarcolemma level causes the triggering of a potential action that results in calcium penetrating the cell, resulting in its growth at the sarcoplasma level, a quantity that is actually insufficient for triggering contraction, but sufficient to promote the opening of calcium channels at the level of sarcoplasmic reticulum, followed by a significant increase of intracellular calcium (from 10 at the power -7 to 10 at -5 mol / L) in the amount needed for triggering contraction.

The mineral element Calcium is bound to Troponin C causing the movement of tropomyosin from its attachment situs at the actin level, exposing this situs. The S1 meromyosin fragment will be fixed at this level, resulting in the change of the angle between the 2 myosin parts, namely its head and neck. Thus, actin is drawn towards the middle of the sarcomere, sliding between myosin filaments. The so-called coupling of actin with myosin is achieved, followed by the release of diphosphate adenosine (ADP) and inorganic phosphate on the myosin head. The breaking of the connection between actin and myosin requires the presence of ATP which is attached to the myosin head and will detach from the actin.

In order to achieve relaxation, calcium must return to its rest concentration, which is done through several mechanisms:
- Re-uptake Ca at the level of the sarcoplasmic reticulum (RS) through the action of the Ca pump at its level;
- Removing Ca from the cell by the Na-Ca sarcolemma antiport mechanism and through the action of the sarcolemma pump.

As a result of muscle contraction through means of tendons, the movement of bone segments is achieved. Skeletal functions are not limited only to those of mechanical support or support of the entire body, but are more complex, as it protects the internal organs, also being at the same time a hematopoetic organ due to its marrow, as well as a reservoir of active calcium and phosphorus ions.

Bone is composed of water, of a mineral phase and of an organic phase. The latter is located in the bone structure in proportion of about 20-25%, being represented in a large amount (over 80%) of type I collagen and non colagenic proteins (osteonectin, osteoprotein, osteopectin, sialoprotein, etc.) and other structures such as: growth factors, lytic enzymes etc. In its turn, collagen is a polypeptide (resulting from the combination of several amino acids of which the most important are lysine and hydroxylated proline) synthesized in osteoblasts which unite 3 peptide chains (2 alpha 1 type and 1 alpha 2 type) with helicoidal structure (this connection is achieved by means of extension peptides that are found on the periphery of polypeptide chains and which, when the collagen molecule is removed from the osteoblast, are detached from it). In addition to osteoblasts, the collagen molecules are united with each other both head to head and also sideways by means of bridges, resulting in collagen fibres. In a very large proportion, of 70-75%, the bone is made up of a mineral phase represented by the hydroxyapatite (crystalscalcium phosphate) which will be disposed between the collagen fibres.

At the bone level we find several types of cells arranged as follows:
- on the surface of the bone there are osteoblasts, cells derived from stem cells in the bone marrow that are metabolically active (with a highly developed endoplasmic reticulum, the place where proteins are synthesized) the collagen synthesis being achieved at their level . They have many receptors for estrogen, parathyroid hormones, the D hormone (Boloşiu, 2008:15) and during development they either suffer the apoptosis process or they become bone lining cells (also placed on the bone surface, taking part in its protection) or turn into osteocytes.
- osteocytes are found in the bone at the level of the mineralized matrix, connected by their extensions, among themselves and with bone lining cells, therewith forming the so-called osteocyte syncytium representing the receptor organ for the mechanical forces which, by acting on the bone, determine the initiation of the remodelling process. The disposal of osteoblasts at bone surface, and also the presence of osteocyte syncytium could explain why the stimulation of the periosteum due to muscle action may trigger bone formation.
- osteoclasts are cells derived from bone marrow hematopoietic cells (more precisely from the monocyte-macrophagocytic lineage) and therefore contain a large number of lytic enzymes (the most important being acid phosphatase and cathepsin K). They are brought by blood to the bone surface, initiating the remodelling process .

These structures are arranged differently, resulting into two types of bone: the cancellous or trabecular bone, which is found in the central portion of the short bones and in the epiphysis of long bones, and the compact or cortical bone, which is found on the surface of bone.

Bone is an organ constantly remodelled through 2 processes: the resorption one, achieved through osteoclasts and the restoration one, made through the action of osteoblasts.

The mechanical stimulation of the bone (loading, muscle contraction) is an important factor in achieving and maintaining bone capital. Following a sustained exercise, there is an increase in osteoblast activity which results in a hypertrophy of the compact and cancellous bone, and also in a consolidation of the bone insertion points of tendons, ligaments and joint capsules.

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Skeletal load restriction (for example in case of a prolonged rest or weightlessness as encountered during cosmic flights etc.) leads to a decrease in bone mass density.

Bone remodelling begins by removing the bone lining cells from the surface of the bone and exposure of the mineralized area through osteocytes lysis in that area (because they have a role in inhibiting bone resorption) by phagocytes, but also through the formation of neoformation vessels in those areas needed to bring resorption cells, (which are transported by blood to the bone).

Speeding traffic in areas which are active during practice exercises, due to increased demand for oxygen and nutrients, could explain the facilitated transport of osteoclasts with the initiation of the remodelling process. The bone mass quantity increases during human growth period until around the age of 25-30 years when it seems to reach the maximum value, enters the plateau and then begins to decrease after the age of 40-50 years.

Along with age, in addition to diminishing bone mass formation, a poor metabolism of vitamin D also occurs, which results in decreased absorption of calcium, decreased calcium levels and installation of secondary hyperparathyroidism which, in its turn, increases bone resorption.

The main problem that arises from the reduction of bone mass is increased susceptibility to fracture. It seems that a 25% reduction of cancellous bone bone mass leads to a resistance decrease of almost 45% (Boloşiu, 2008:24).

The bone resistance is dependent both on the density of the bone mass and on the quality of the bone (on the distribution of bays, cortical thickness, heterogeneity of mineralization etc.). Along with age, we can first notice thinning and disappearance of horizontal bays at the level of the vertebral body, for mechanical stress is lower at their level, with the persistence of the vertical ones over a longer period of time, as at their level mechanical stress is more important due to bipedal resort.

Valuable information about bone structure was obtained using a technique called bone histomorphometry, which consists in tetracycline marking and performing bone biopsies.

Studies have shown that bones behave like crystals due to collagen in their structure. Fukada and co. (1957) demonstrated piezoelectric properties of the bone, due not to hydroxyapatite crystals which are not centrosymmetric, so they do not have such properties, but to collagen fibres. This is due to collagen structure which is formed by the interweaving in triple spiral of 2 alpha 1 chains with one alpha 2 string, merging together by bridges arranged head to head and sideways, thus forming collagen fibrils. Collagen fibres in the bone structure have a very well established guideline.

The basis for the formation of bone mass is represented by the signal that is received at the level of the osteocytary syncytium due to mechanical application of bone, and that triggers the formation of bone. Electrical changes occurring at bone level are due to its anatomical and functional features that determine the onset of a piezoelectric effect. The name comes from the Greek word "piezo" which means to press. Thus, the direct piezoelectric effect consists in the property of crystals to charge with electric charge on some of their sides when subjected to tensile or compressive task in a certain direction. The inverse piezoelectric effect is also called electrostriction and is represented by the property of crystals to deform in certain directions, if there is a difference of potential on some of their sides. The size of electric charge is proportional to the applied force. Through the action of forces F on the mechanical axis, the network also deforms and the centres of gravity of particles with negative charges and of particles with positive charges no longer coincide. An electric dipolar moment arises and hence the polarization of electrical charge which, in the case of the bone, triggers the formation of bone mass.

The first information about the use of electricity for strengthening a fracture apparently dates back to 1841, being reported by Hartshorne who describes a person with tibia fracture being treated with electric shock in 1812 for 6 weeks. Currently, more and more laboratories are studying the effects of electric current (DC, electromagnetic stimulation etc.) on bone and cartilage (Bringhton, 1981).

Collagen is a protein structure, in which molecules are equally well established, being at a distance of 0, 1D, 2D, 3D, 4D from neighbouring molecules, where D = 1/4, 4 of the length of the molecule . It is a coaxial system consisting of proteins (the most important being lysine and proline in the hydroxylated form) and a matrix made of hyaluronate and proteoglycans. An electrical phenomenon occurs when proteoglycans move among collagen fibres. (Norman,http://www.normanallan.com/Sci/Crystals.html).

There are 2 independent mechanisms responsible for the electromechanical behaviour of the bone: piezoelectric and electro kinetic. The first is related to the emergence of a separation of electric load at the level of bone matrix and the second one involves potential arising from the consolidation of bone matrix during deformation.

Studies on the mechanical behaviour of bone during action potential generating mechanic stress, by using microelectrodes, showed that bone generated potential has an intensity of 1-2 magnitude orders (10-100 times higher than that measured at the macro level through determining average values of the electric fields) (Pollack, 1979).

When we move, we change the load degree at bone level, causing the appearance of differences in

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potential. If this move is made in the presence of a strong magnetic field like the one generated by Earth, these effects are magnified. Thus, placing such a structure in a magnetic field as the one produced by Earth will determine the interaction with it and it could explain certain phenomena such as * magnetic pass * therapy, but also the necessity of gravity for bone formation.

Studies carried out at the University of Pennsylvania between 1970 and 1980 showed that the application of an electric current can cause both formation and resorption of bone mass, depending on the polarity of the used current. According to the theory of Arndt-Schulz (http://en.wikipedia.org), the same external stimulus, depending on its intensity, may cause excitation, inhibition or may destroy the biological structure on which it acts.

The study on the effect resulting from the application of one uniform compression and of an uneven one on the cortical bone, carried out by Iannacone and co. (1979) and published in the Journal of Biomedical Materials Research, demonstrated the production of differences in potential, caused by mechanical stress following the uneven compression, whereas, in the case of uniform compression, electric fields around osteons were equivalent and did not reveal a difference in potential. Also, the value of electrical potential was different depending on the region on which uneven compression is applied. In their turn, intra-osteon potentials obtained are uneven: a potential decrease has been observed at the level of Haversian canals, close to the compressed side, and their growth on the opposite, tensioned side of the bone.

Experiments conducted by McElhaney on a human femur that was dried by exposure to 105 degrees for 2 weeks and at whose level 600 microelectrodes were mounted, showed a different bone behaviour depending on how the compressive forces acted: areas in which bone mass was produced and areas where bone resorption occurred. Implanted platinum electrodes were used to eliminate corrosion, mounted inside the bone about 6 inches above and below the fracture. It seems that the effect of the used current is to increase the number of osteoblasts in the fractured area.

Therefore, tendon traction exerted by different types of muscle contraction performed under different conditions (starting position, duration, intensity, etc.) will cause different effects on the bone.

There are three types of muscle contractions:

- the isometric contraction, in which, as the name tells, the length of the muscle remains the same, but muscle tension increases. This contraction is achieved without moving the segment.

- the isotonic contraction, through which the tension remains approximately constant while the muscle length changes either in the sense of shortening -concentric contraction, or in the sense of elongation - eccentric contraction. This type of contraction thus causes the movement of the segment.

- the isokinetic contraction is also a dynamic contraction that is achieved by applying a slightly variable resistance so as to cause a constant motion speed and a constant force throughout the entire motion range.

Studies have shown that, out of these contractions, the greater ability to generate force is achieved by the eccentric contraction, then by the isometric one and the least by the concentric one, while if we compare the effect to energy consumption, the best performance is achieved by the isometric contraction, followed by the eccentric one.

By combining the use of patient drug therapy with appropriate kinetic programs, it is aimed to achieve a reduction in drug therapy, which would have major implications both in managing the diseases of a person with osteoporosis (limiting adverse effects, polimedication, certain contraindications, etc.), but also financially by reducing costs.

Last but not least, increasing bone mass or maintaining it through a well performed kinetic program can be a physiological way to improve an important medical problem, which occupies a leading position in bone diseases of the elderly. From the above mentioned issues, it appears that this scientific approach has a practical, a medical and an economic importance.

We intend to use the research results as a basis for drawing up kinetic programs aimed at people with osteoporosis, who present risk factors for developing this disease or risk factors for falls.

Conclusions

1. The highlighting of the main structures involved in achieving movement (nervous system, muscular system and skeletal system) and also of their anatomo -functional characteristics, allows us to understand the mechanisms underlying movement.

2. The lack of movement causes a series of changes in the body, which may even lead to death.

3. Movement, due to traction exerted on the collagen fibres in bone structure, is the stimulus needed to trigger the bone mass formation process.

4. The implementation of certain kinetic programs adapted to clinical features of patients with osteoporosis or at risk of osteoporosis, may favourably influence their evolution and, at the same time, cause a decrease in costs needed for carrying out their primary and secondary prevention.

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