ANALYSIS OF RADIOLOGICAL CHARACTERISTICS DISTRIBUTION IN THE VERTEBRAL BODIES OF THE LUMBOSACRAL SPINE OF COMPETITIVE ROWERS

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ABSTRACT: Unfavorable biomechanical situations, usually related to the performance of a profession and competitive sports practice, promote formation of overloads. This problem may be particularly perceptible among sportsmen that practice strength and stamina sports. The present study deals with rowing. The purpose of this study is to evaluate the degree of degenerative changes of the lumbosacral spine in competitive rowers, on the basis of an analysis of changes in the cancellous structure of vertebral bodies. This has been achieved on the basis of radiological density acquired from a CT test.

KEY WORDS: lumbar spine, overload, biomechanics, rowing, radiological density

INTRODUCTION

A growing number of the ill suffering from spine pain constitutes a serious medical and social problem [1-4]. Usefulness and efficiency of prophylactic and therapeutic proceedings in spine illnesses depends on the study of causes and emergence mechanisms of deformations and functional disorders of the spine. Apart from causes known to clinical practice, mechanical factors have a significant influence on the occurrence of spine pain dysfunctions.

From the point of view of load transmission, the most important is the morphology of the lumbar spine, which is characterized by the highest degree of bend (if one does not take into account the bend of the sacrum). Unfavorable biomechanical situations usually related to the performance of a profession and competitive sports practice promote the formation of overloads [5]. Any kind of competitive sport that results in prolonged, one-sided, nonphysiological training, causes overloads of the kinetic apparatus resulting in negative effects for the spine. It is especially noticeable in case of athletes practicing strength and strength-endurance sports, where under the influence of excessive loads there occurs a transgression of the physical endurance as well as the adaptive ability and functional efficiency of the ligaments, joints and bones. The present study deals with rowing. Overload lesions in the athletes have a direct relation to the formation of morphological damage (degenerative changes) e.g. in the area of intervertebral discs. The group of the tested rowers (Table 1) revealed serious pathological changes of the intervertebral disc [19].

If degenerative changes of the discs occurred, this means that they were preceded by functional disorders of the muscular system and soft tissue e.g. ligaments, joint capsules etc. and that they may result in morphological changes in the bone tissues. Due to the character of the loads it has been predicted that - specially among rowers - inhomogeneity of the structure can be observed, even more so in case of the tissues of the spine.

In regard to the above, it has been considered necessary to examine possible structural changes in the vertebral bodies. It has been achieved on the basis of radio-density acquired by means of CT.

MATERIALS AND METHODS

The research material consisted of 20 athletes from the national team aged 21 to 33, practicing competitive rowing with symmetrical sculling oars. The athletes have been practicing competitive rowing for 8 to 20 years. During the initial interview sixteen of the twenty examined athletes complained of recurrences of pains. The pains occur suddenly and are acute in nature.

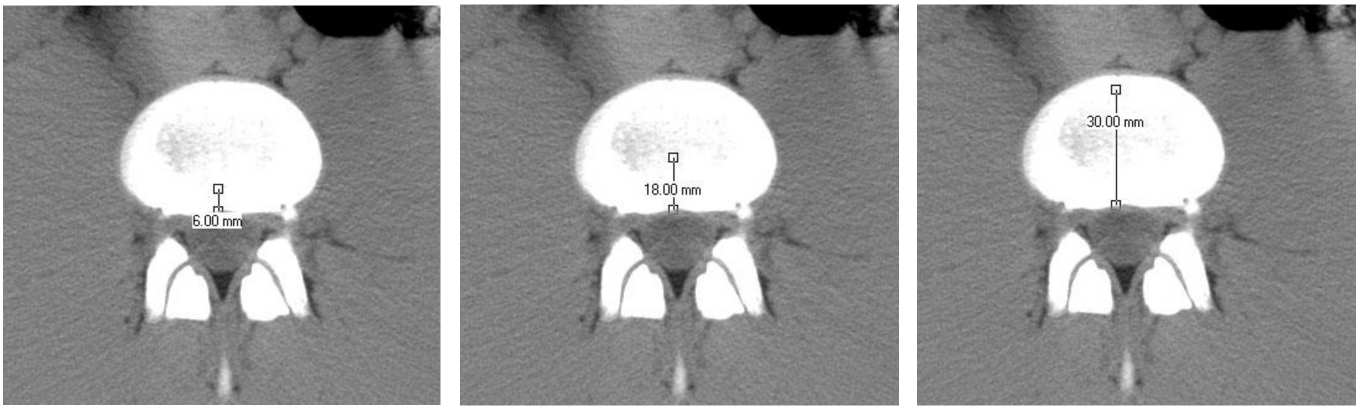

FIG 1. EXAMPLE OF A TOMOGRAM PRODUCED BY THE CT SCAN OF THE ROWERS - RADIOLOGICAL DENSITY MEASUREMENT POINT (ρ_{Pi}) TOGETHER WITH ITS DISTANCE FROM THE SPINAL CORD CANAL (XPI)

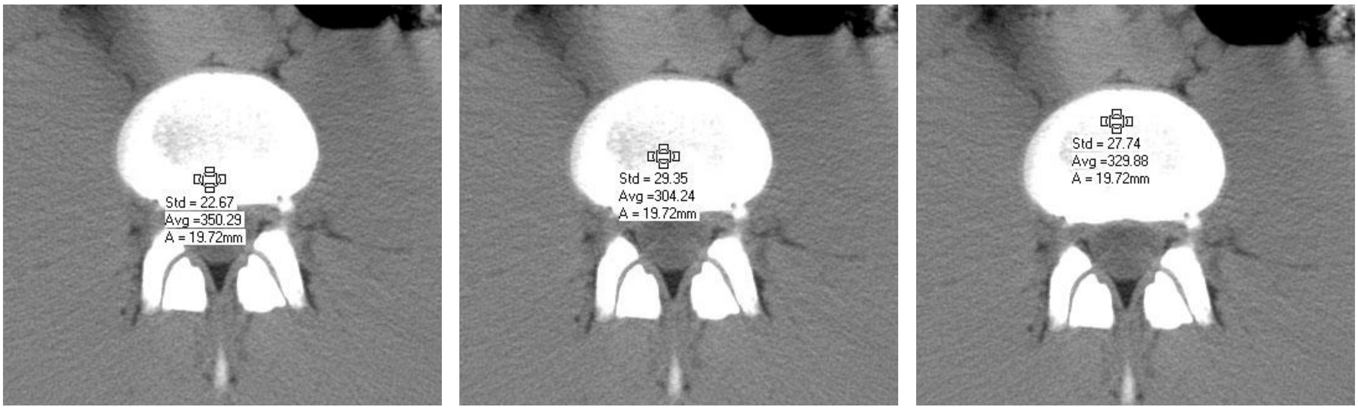

FIG 2. EXAMPLE OF A TOMOGRAM PRODUCED BY THE CT SCAN OF THE ROWERS - RADIOLOGICAL DENSITY MEASUREMENT ρ_{Pi} (AVG), STANDARD DEVIATION (STD) AND AREA (A) USED FOR DENSITY MEASUREMENT

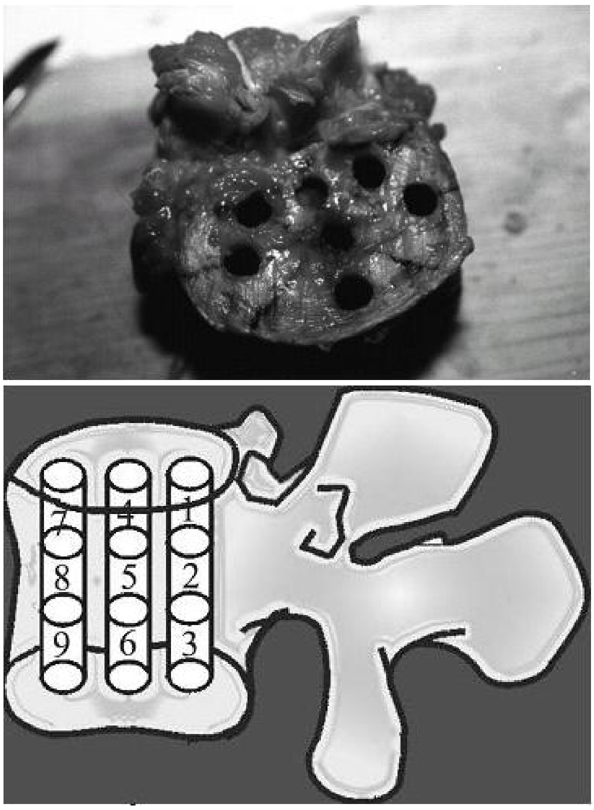

FIG 3. THE DIAGRAM OF RADIOLOGICAL DENSITY MEASUREMENT POINT IN VERTEBRAL BODY (RPI) IN THE SAGITTAL PLANE (AUTHOR'S METHOD [6])

The comparative group consisted of radiologically examined specimens of human vertebrae of the L1 to L5 lumbar spine. The author assumed, that only such specimens shall be used that show no pathological changes, are taken from fresh cadavers of mature donors (15 males) aged 25 to 32, in the first twenty-four hours after their death. In all the cases the preparation and storage of the specimens was identical. The radiological tests were conducted over 975 specimens [17,18]. The characteristics of the research material have been gathered in Table 1.

The research consisted in analysis of tomographic images obtained as a result of CT tests.The bone tissue shows a very heterogeneous structure [17,18], that is why radio-density, whose distribution is recorded by the computer tomograph, assumes different values [17,18].

The numerical data obtained in this part of the experiment were statistically analyzed with direct reading of standard deviation of particular values of radio-density. Fig. 3 presents schematically the radio-density measurement points.

The tests were carried out in 900 measurement points (samples) of the cancellous tissue of the vertebral body of all rowers. On the basis of the CT data, radio-density value was established from the area of $1.96 \cdot 10^{-6}$ [m^2] for three parallel layers $1 \cdot 10^{-2}$ [m] thick, located at a distance of (XPi) from the spinal cord canal, respectively: $0.6 \cdot 10^{-2}$ [m], $1.8 \cdot 10^{-2}$ [m], $3.0 \cdot 10^{-2}$ [m], (Fig. 1, Fig. 2).

TABLE I. THE CHARACTERISTICS OF THE RESEARCH MATERIAL

	Training	Age	Height	Body Mass
avarage	12.8	26.9	194.6	92.1
min-max	8 - 20	21 - 34	185 - 205	75 - 104

Figs. 1 and 2 present sample tomograms, where radio-density measurement points, standard deviation and reading area were marked.

RESULTS

Distribution of radio-density in the vertebral body of athletes practicing rowing. The values of radio-density of the vertebral bodies of competitive rowers obtained in the study were presented in graphical form. Individual measurement points were marked [ρ_{Pi}], in successive lumbar vertebrae L1-L5 (Fig. 4).

Whereas, Fig. 5 presents the distribution of radio-density of particular vertebrae of the lumbar spine, which form the comparative material [17], adopted as standard. The above material was collected on the basis of data obtained from previous research [17], conducted on healthy spines of untrained subjects.

On the basis of comparison of the values obtained from the group of athletes to the radio-density adopted as the standard [17], in all vertebrae of the L1 – L5 section of the spine one can observe the phenomenon of structure transformation aiming at its densification. Depending on the measurement point, the bone tissue density increases in competitive rowers by a maximum of 63% (L5/1) of the value adopted as the standard (Fig. 5). One may also observe that the L5/1 sample forms the area that in healthy untrained subjects belongs to the cancellous part of the bone tissue of the vertebral body. However, after a long term period of high-performance training (rowing), the bone tissue in this area undergoes transformation into structure whose radio-density resembles that of the compact (cortical) tissue. Also in case of the vertebrae L4, L3, L2 a recurrent, as indicated above, area of the vertebral body, where the radio-density value corresponds to the one of a cortical and not a cancellous tissue, was observed.

One may assume that the above result is strictly related to the pathological changes, which have occurred earlier in the intervertebral disc [20], as a result of cyclical load acting on the L1 – L5 section, typical to rowing [9,18,23]. The above changes have already been described in study [19]. It should be repeated that the CT examination of the discs in the tested athletes proved the existence of: two-sided hernia with pressure on the meningeal sac - the diagnosis has been confirmed by a radiologist.

Moreover, it is worth stressing the fact that in agreement with earlier presumptions, during the comparison of radio-density, according to the number of successive lumbar vertebra, the greatest changes in density of the bones were observed in the last lumbar vertebrae L4 and L5. In particular measurement points, an average increase of ρ by ca 35% over the standard value was recorded.

Within the group of samples (7-9) located in the anterior part of the body of all lumbar vertebrae, a larger value of density was always observed in case of samples nr 7 located in the highest part of the vertebral body (Fig. 4).

The smallest changes in the structure of the bone tissue were observed in the first lumbar vertebra L1.

In the vertebral body areas [2,5,8] a characteristic, fully repeatable behavior of the bone tissue was observed (Fig. 4). The author found that it is the only place in the vertebral body where the value ρ obtained from a CT of the competitive rowers is comparable to the data adopted as the standard [17,18]. Particularly in the measurement point marked with nr 2, exceptionally low values of radio-density are observed. They stay within the range of 140 to 180, at an average standard deviation of $S\ |\rho| = \pm 20$.

It should be stressed that these results, showing an exceptionally low value of radio-density, repeated in all the examined vertebral bodies [17,18]. Consequently, the author searched for the reason of this situation in bone physiology. On the basis of data [22], the author's theory on the existence of a nutrient canal within the discussed area was confirmed. It should be stressed that a profound analysis of world literature shows great deficiency in the subject of vertebral nutrition. Only Schnuerer [22], in his atlas of anatomy (electronic version), presented a diagram of the vertebra (Fig. 6), which shows that it is nourished by blood vessels that enter from the side of the vertebral canal, disappearing towards the anterior part of the vertebra. This may justify the occurrence of similar values ρ in the areas [2,5,8], with predominance of sample nr 2.

As a result of research (Figs. 4 and 5) conducted with the use of CT, one may observe that within the group of tested athletes, in case

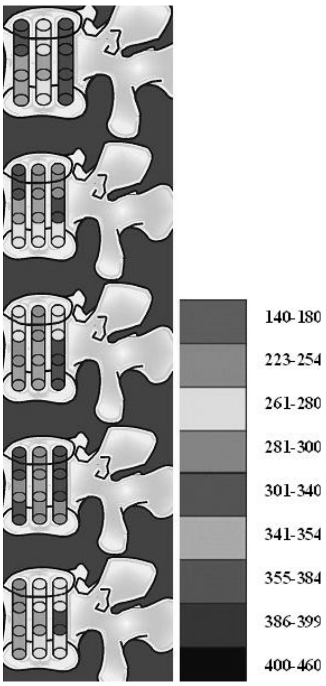

FIG 4. DISTRIBUTION OF RADIOLOGICAL DENSITY IN A GROUP OF ATHLETES PRACTICING COMPETITIVE ROWING

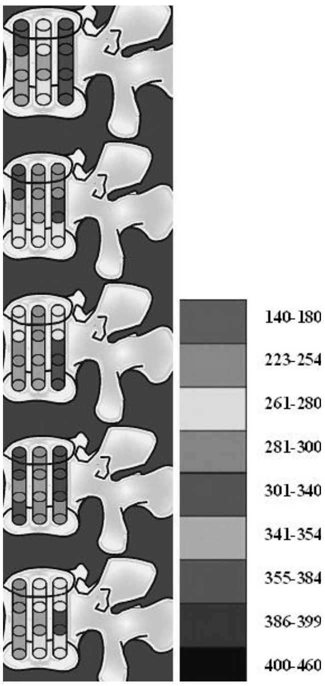

FIG 5. THE DISTRIBUTION OF RADIO-DENSITY - THE STANDARDS [17]

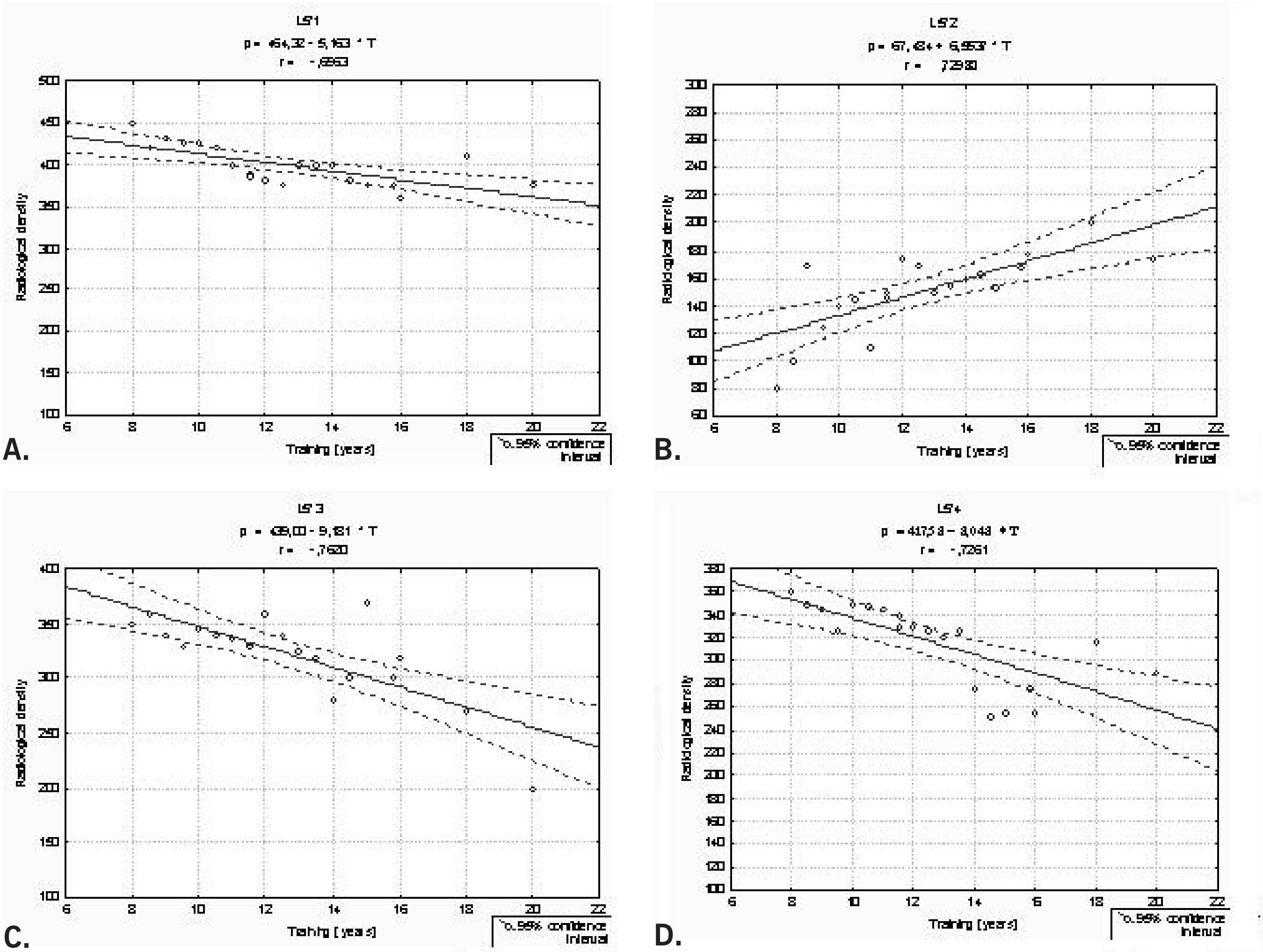

FIG 6. THE RADIOLOGICAL DENSITY OF THE BONE TISSUE OF THE VERTEBRA IN RELATION TO THE NUMBER OF YEARS OF TRAINING IN SAMPLE AREAS: A. L5/1, B. L5/2, C. L5/3 D. L5/4

of all lumbar vertebrae it is impossible to determine an average density value ρ for the entire vertebral body, since too great differences were obtained in the so called point density of the vertebral body.

Relation between radio-density of vertebral bodies in rowers and their training period. The author also studied the changes in the density of the bone tissue of vertebral bodies in the lumbar spine of athletes, in relation to the number of years of competitive rowing practice (W). Figures 6.A. to 6.D. present examples of such relationship for samples located in L5 vertebra.

Each vertebra had 9 measurement points of dependence ρ(W). The obtained ρ(W) relations were approximated with linear functions. All obtained dependences (e.g. Fig.6.A to 6.D) are statistically significant at $p<0.05$. In all the examined areas of the vertebral bodies L1 to L5, the author found that rowers are a group of athletes, who after eight years of intensive high-performance training achieve the greatest increase in radio-density of the cancellous tissue of the vertebra.

After comparing the charts for vertebra L1-L5, in all the examined areas, except L1/2-L5/2 and L1/5-L5/5, the author noticed a negative correlation between the radio-density of the bone tissue of the vertebra and the number of years of competitive rowing practice. That is to say, along with the increase in years of competitive rowing practice there occurs a decrease in the average radio-density of the bodies of lumbar vertebrae.

For the vertebrae L3-L5, where a clear increase in radio-density of the cancellous part of the vertebra, towards values corresponding to the cortical tissue (Fig. 6), during the next 12 years of training, there occurs a decrease in radio-density.

It should be noted that for areas located in the highest (1, 4, 7) and the lowest (3, 6, 9) regions of the vertebral body, a correlation of dependencies ρ(T) was obtained, according to the scale used in statistical analysis, that equaled respectively:

- •high $0.5 \leq rxy < 0.7$ - for vertebra L5 (see Fig. 6. A-6.D)
- •average $0.3 \leq rxy < 0.5$ - for vertebrae L3 and L4
- •low $0.1 \leq rxy < 0.3$ - for vertebrae L1 and L2

- no correlation between number of years of training and decrease in radio-density of the cancellous tissue of the vertebra.

It should be noted that in the area of the vertebral body located in the middle of the height of vertebrae (2, 5, 8), repeatability of the change in ρ(W) was observed across the entire group of rowers. Contrary to the remaining samples, in the above area, a positive correlation of the discussed dependency was obtained – i.e.

the increase in the years of competitive rowing practice corresponds to the increase in the average values of radio-density. The above relationship is especially noticeable in case of sample nr 2 (Fig. 6.B).

DISCUSSION

The results obtained in this study confirm the existence of biomechanical changes of the vertebrae in athletes practicing professional rowing. The author found a clear increase in radio-density of the cancellous tissue in the vertebral bodies of the lumbar spine, going up towards levels corresponding to the ones of a compact bone. The athletes reach maximum density in specific points of the vertebral body after only eight years of training loads (Fig.6).

For comparison, let us observe an opposite phenomenon. Practice indicates that where there are no gravitational forces (outer space), the bone tissue quickly loses its density [26]. That is why astronauts that come back to Earth after a long period of time do not leave the spaceships themselves but are rather carried out of them to prevent fractures. Athletes that practice e.g. competitive rowing are in an exactly opposite situation. They are subject to large overloads, which cause an increase in radio-density of the bones in places where there is a concentration of these overloads.

For a precise explanation of problems related to the structural modification of bones subjected to sustained overloads, one should analyze the issue of bone overgrowth after fractures.

There exist several hypotheses that explain this phenomenon. However, they have not been thoroughly verified. In an attempt to explain the obtained results, one should first of all observe that bones constitute a complex system in both structural and functional way, which is composed of chemical substances that are in 1/3 organic and in 2/3 nonorganic (calcium phosphates). A basic nonorganic component of the bones is hydroxyapatite [24]. A bone owes its special mechanical properties to the process of embedding of calcium phosphates in the soft fibrous intercellular matter. The complex physiological and metabolic relations that exist in the organism have an equally important influence on the biomechanical characteristics of the bone tissue. Bone is a metabolically active structure capable of dynamic adaptation. The active structure of a bone is composed of bone resorbing cells (osteoclasts) and bone building cells (osteoblasts) as well as intercellular matter called the bone matrix [24]. The task of osteoclasts is to search for parts of the bone tissue that require renovation. Osteoclasts dissolve worn out bone cells and as a result empty space forms in their place. Subsequently osteoblasts proceed towards these places and fill it with new bone tissue. In this way bones possess extraordinary properties, such as adjustment of their parameters to mechanical requirements and ability of selfrepair in case of damage. This process is called „bone remodeling"

Bone density, and therefore resistance, which is related to it, decreases after a prolonged period of relief and increases as a result of intensive training [24,25] (load); this can be witnessed clearly in rowing.

The course of the process of concrescence and modification of the bone tissue structure depends on anatomical structure, cellular composition and the biochemical processes that take place. In order to asses the resistance of such material during sudden impact or load, e.g. those typical to the discussed group of athletes, materials science introduces measurement of the so called critical stress intensity factor (for brittle bodies). It describes the resistance of a material to expansion of microfractures, combined with energy absorption and inhibition of this process. For an overloaded bone, this means that if the elastic energy limit is exceeded (mainly compact bone), the absorption of excessive energy occurs through creation of a system of microfractures in hydroxyapatite fibers (i.e. cancellous bone) and it does not result in apparent fracture or fracture-dislocation. Relief of tension leads immediately to substantial disappearance of microfractures [6] and biological repair processes may restore the bone to its original state.

As a result, one may hypothesize that during the life of a man, continuous processes of microfractures of a certain number of bone trabeculae accompanied by their permanent regeneration occur.

It is a well known fact that the mechanical environment to a large degree influences the process of concrescence of a fractured bone [16]. Insufficient stabilization, related to preservation of interfraction motion or considerable dislocation of the fractions may delay the concrescence processes. In the past, the states of frequent complications occurred in patients that did not obtain enough stabilization of the fractures [12,14,21]. At the same time, as far as maintaining considerable degree of motion leads to concrescence disturbance, in situations where controlled rhythmically repeated micromotions or controlled distraction of fractions occur, acceleration of bone callus creation is observed [8,10,11,15]. On the basis of these observations it is assumed that the growth rate and quality of the created bone concrescence may be stimulated by a properly applied strategic mechanical environment.

One may not disregard another defense mechanism of the bones against excessive overload, which was observed among competitive rowers. Both hydroxyapatite, as well as collagen, grown together in form of fibers are piezoelectric bodies, i.e., their microcrystals may transform mechanical energy into electrical energy (through charging and distribution of the charges on the surface of the crystal).

The rowers exhibited reduction in density that became more serious along years of rowing practice. Some of these changes were adaptative changes, that is the physiological process of biological compensation of the vertebrae subjected to loads. Literature data [15] indicates that beyond the age of 26, the average size of hydroxyapatite crystals decreases. Therefore, aging seems to be related to more intensive crystallization of the bones.

Another issue the author focuses on is the extremely low value of radio-density (repeated in each vertebra) in ½ of the height of the vertebral body (samples nr 2 and 5, 8). Especially in case of sample nr 2 located in the nearest neighborhood of the spinal cord canal.

As indicated in the study [22], the vertebra is nourished by blood vessels, that enter from the side of the vertebral canal, disappearing towards the anterior part of the vertebra. That is the source of similar ρ values in area (2, 5, 8) with the advantage of sample nr 2. The blood vessels enter from the side of the vertebral canal, and nourish the vertebrae, disappearing towards their anterior part.

One should notice that the areas of the body that are located directly over a nutrient canal undergo the strongest modification. Taking into account the entire vertebra - optimum adaptation of the cancellous structure to the load program occurs. The bone tissue adapts to the overload scheme and thus protects the nutrient canal, minimizing its deformation. The distribution of the rigidity of the vertebra is optimized, which ensures the smallest deformation of the nutrient canal.

Another characteristic fact is that these samples demonstrated positive correlation between radio-density and the number of years of training. Radio-density increases along the years of training in places where the vertebra is nourished. This fact is directly related, over an accordingly longer period of time, to the supersession of vascularized nutrient canals by the growing bone callus.

Clinical observations [25] prove that the amount of bone callus that originates during concrescence, is proportional to the amplitude of micromovements maintained in the crack. In case of rigid fixation (protects from local canal load) the bone density value is exceptionally low. However in case of prolonged loading, micromovements are transferred to the most protected parts of the vertebral body. As a result, additional bone callus grows and the density of the bone increases. This process is dangerous for the athletes, who practice competitive rowing for many years and thus aim at irreversible degeneration (necrosis) of the vertebrae. This is obviously caused by insufficient „nourishment" of the vertebrae.

CONCLUSIONS

1. Biomechanical analysis of spine loads and new techniques and methods for the testing of the state of spine tissue structure let us prove that competitive rowing practice in its present form leads to permanent overload lesions of the lumbar spine.
2. The author demonstrated that there is no quantitative, unambiguous proof that would explain the effect of increase in cancellous tissue density of the vertebral bodies, which was observed in rowers, and which aims at ρ values corresponding to the ones of cortical bone. Hypotheses that suggest possible explanations of this fact are discussed.
3. Many years of competitive rowing practice results in „necrosis" of the vertebrae caused by insufficient „nourishment".

Rowing is one of these competitive sports that require intensive training, which results in definitely negative consequences for the spine. The choice of sports career in rowing must be accompanied by the idea of „conscious training". The coach, and especially the athlete himself, must be aware of the fact that rowing results in great spine overloads. Therefore, during training, the exercises should be directed not only at the muscle group that performs the work related to obtaining the best sport result, but also at the muscle group that is responsible for unburdening the lumbar spine.

Systematic repetition of this type of „rehabilitation exercises" shall not only prevent spine overload but also the resulting diseases.

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