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EVALUATION METHODS OF BONE CONDITION

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Abstract: The article presents research methods for bone damage diagnosis by osteoporosis. We describe in detail densitometric methods such as DEXA tests, SXA method, Quantitative Computed Tomography (QCT) and Quantitative UltraSound (QUS) method. In this article we evaluated to problems concerning in diagnosis and the availability of diagnostic equipments.

1 Introduction

The person has bones in the best physiological state between 20-40 years old. When a bone fracture occurs, the process of its reconstruction occurs. This means that the bone itself can replace damaged structures. Low-energy fractures are most common in people with increasing age. It is mainly about the fractures of the spine, the neck of the femur and the wrist. A low-energy break is a fracture caused by the relatively small forces that would not occur under normal conditions, ie without tissue weakening. The cause of the fracture is the lack of bone remodelling itself. One of the causes is calcium depletion. It is a condition where bone absorbs calcium more quickly and its replenishment is relatively slow. The bones lose their density. Osteoporosis is most diagnosed in the case of a first fracture. Osteoporosis develops asymptomatically, relieving the skeleton of stored calcium sources. Patients who have already had their first fractures and at-risk patients will be selected for a series of tests to diagnose osteoporosis. Therefore, these tests can be divided into four main categories (Figure 1).

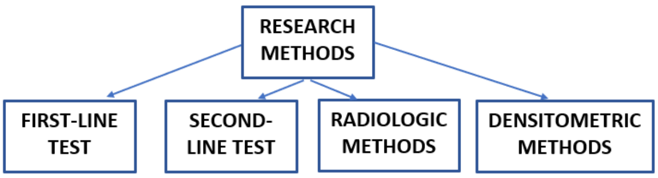

Figure 1: Bone research methods for the diagnosis of osteoporosis

The **first-line tests** include the determination of ESR (*erythrocyte sedimentation rate*) levels, alkaline phosphatase activity and the levels calcium and phosphorus in serum. The erythrocyte sedimentation rate (ESR) is a measure of the rate at which red blood cells fall and is an indicator of a possible inflammation. Basic alkaline phosphatase is an enzyme found in bones, liver and intestines [1].

The **second-line tests** may include tests for monoclonal protein in blood to exclude multiple myeloma, PTH concentration (Parathormone is a parathyroid hormone responsible for calcium-phosphate metabolism), 1,25$(OH)_2$D, and osteocalcin which demonstrates the quality of bone turnover. And the determination of levels of calcium and hydroxyproline excreted from urine [2].

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2 Methodology

Radiologic methods are based on the use of X-rays. Osteoporosis is most often diagnosed by detecting typical fractures or deformities, especially within the vertebrae. Lesions occurring before a fracture has occurred are visible only in the case of the loss in bone mass of the order of 30 ÷ 50%. The most common fractures occur in the lower and upper bone shafts. Further development of osteoporosis results in wedge shaped fractures occurring in the front parts, most often in the thorax. In the last stage of the disease, frequent occurrence of vertebrae crushes, i.e. compression fractures were observed. X-ray based methods do not allow for a direct quantitative analysis of bone calcification, and any evaluation attempts depend significantly on the subjective opinion of a radiologist evaluating the image. Individual parameters of X-ray emitting lamps also affect the evaluation possibilities. However, tests of this group may be enough to diagnose osteopenia, i.e. local diminished bone density, which is the basis for ordering further densitometry tests [3-5].

Densitometric tests are designed to determine the quantitative bone loss. The tests in this group consist of measuring the amount of absorbed X-ray that passes through the examined bones by comparing the amount of radiated energy and the amount that reaches the detector. Densitometric tests can be divided by the location of the measurements: SXA, QCT, QUS and DEXA (Figure 2). Densitometric tests use significantly lower radiation doses than standard x-ray examinations [6-9].

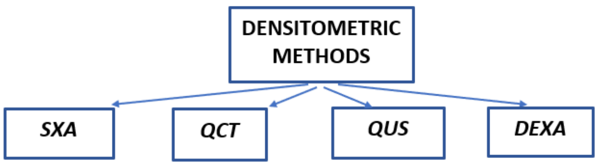

Figure 2: Densitometric tests by the location of measurements, where SXA – (Single Energy X-ray Absorptiometer); QCT – (Quantitative Computed Tomography); QUS – (Quantitative UltraSound); DEXA – (Dual Energy X-ray Absorptiometry)

The ***DEXA*** tests (Dual Energy X-ray Absorptiometry) - allow the evaluation of density parameters of central parts of the skeleton. Tests in this group are called bi-energetic X-ray densitometry. They are used to analyse the density of the lumbar spine, the femur, and to determine the average density of the entire skeleton. In this test method, the BMD (*Bone Mineral Density)* parameter, expressed in [g/m^3], is determined. The result may be presented in three forms and is a reference for former tests for a given population. Two of the forms are expressed as percentage values. The first one is the reference for the bones of the young (% young adult), whereas the second - is the reference for the peak bone density (% age matched), or in a form of a number of standard deviations (Z-score), which refers to gender and age [10,11].

The most studied human motoric organ is the spine in the lumbar region and the femur (right or left). Diagnosed areas in the spine are most often selected due to their presence in both trabecular and solid structures. Areas of the femur are examined due to the most commonly occurring fractures. In these areas, osteoporosis can be diagnosed by defining a standard deviation below T-Score -2,5 [12].

With the DEXA X-ray densitometry method, the radiation beam consists of isolated groups of low and high energy photons that allow bone analysis neglecting the soft tissue composition. A narrow-angle fan beam is used which, after passing through the tissue, falls on the scintillator which allows further segmentation of the image. The basic element of the densitometer is X-ray micro tube and a sensor measuring the intensity of radiation [13].

Contrary to the single energy X-ray absorptiometer (***SXA***) method, in this method the tested areas do not need to be immersed in water to eliminate the effect of soft tissue. The DEXA (Dual Energy X-ray Absorptiometry) uses alternating low and high energy radiation. The absorption of these types of radiation is significantly different for soft tissues and almost identical for bones. The separation between the spongy and compact osseous tissues is not taken into consideration in the analysis. Based on these differences between bones and the surrounding tissues, the influence of soft tissue is eliminated. The DEXA densitometers are also available in peripheral versions for examining the bones of the forearm, phalanges and heels. They practically replaced the SXA apparatuses in the market. The main disadvantage of peripheral densitometry is the lack of ability to perform examinations of the vertebral and the proximal part of the femur, i.e. areas where earliest bone losses occur and where life-threatening fractures are most common [14].

Quantitative Computed Tomography (***QCT***) uses much higher doses of ionizing radiation than DEXA densitometers. The radiation source revolves around the patient's body, and the output radiation is recorded by the detector matrix. The test is more burdensome for the patient but allows the determination of the actual bone density expressed in mg/m^3. However, its cost significantly outweighs other diagnostic methods. The density value is analysed directly for each voxel. It is possible to evaluate separately the properties of the cortical bone, and separately – of the compacted bone. Appliances for this type of tests are dedicated appliances, or ordinary computer tomographs with additional software [15].

The Quantitative UltraSound (***QUS***) method is used for testing of the patella, the phalanges or the heel, i.e. in areas where there is little surrounding soft tissue [16].

The examination includes two parameters, i.e. the speed of sound (SOS) and the Broadband Ultrasound Attenuation (BUA). SOS is the velocity of the ultrasonic wave that changes while penetrating bone structures thus reflecting the density of the bone. BUA is the weakening of the ultrasonic wave dependant mainly on the bone structure, i.e. the trabecular thickness, the number of inter-trabecular spaces and the direction of the arrangement. The test results based on ultrasound are significantly different from those obtained using RTG radiation, but the method is much cheaper and simpler. Ultrasonography is mainly used in screening. An ultrasound transducer emits ultrasounds (with the use of piezoelectric elements). On the other side of the tested object, there is a sensor that measures the values of the beam after its passage through the bone. Acoustic properties of the bone are determined. The more porous and heterogeneous it is, the greater is the weakening and the slowing of the beam [17,18].

3 Problems in diagnosis and availability of diagnostic equipment

It is the primary care physicians who can most effectively reach the population at risk of damage bone, identify the disease and treat it. In many health care's centres, doctors do not have enough time to thoroughly examine a patient. Medical interviews are not carried out precisely enough because of long queues of patients. Doctors are reluctant to direct patients for additional, adjunctive testing that can accurately diagnose osteoporosis. The main reason lies in financial resources, but also in doctors' inadequate knowledge. Medical centres, in order to save on specialized tests, usually send patients to x-rays (*RTG – Radioisotope Thermoelectric Generator or roentgenogram).* As a rule, medical centres are equipped with such devices, which minimize the cost of sending patients to more specialized tests, especially if they are to be performed by their competitors. A patient who goes to see their GP is sent to an RTG in the first place. A radiology technician performs an x-ray, and a radiology doctor describes the changes visible in the image. It is assumed that osteoporosis-specific radiological changes are only visible when 30% to 50% of bone mass has been lost. It should be noted that X-ray is not the appropriate method for determining the degree of bone loss without fractures. The test does not allow for the quantitative analysis of the skeleton calcification. Radiologists with longer work experience determine minor bone decay as osteopenia and advanced stages of bone changes as osteoporosis. Thinner bodies mean the reduction of the thickness of their spinal cord border as well as vertical bands characterizing disappearance of the horizontal trabeculae in the bone structure may suggest low bone mass. The assessment of such changes is often subjective and largely depends on the setting of the X-ray tube parameters [19].

The availability of specialized examinations for the patient is also problematic. In most cases, osteoporosis is diagnosed only after a pathologic fracture, so at the stage where there is significant bone mass loss and bone weakening. The prevention and screening system for the possible largest number of patients, especially those with the highest risk, should be implemented. National healthcare institutions should develop a system based on cheaper test methods, safer, more repeatable and more precise, i.e. methods which would combine the advantages of ultrasonographic tests and x-ray [20,21].

4 Summary and conclusion

There are a considerable number of diseases weakening the mechanical properties of bones in humans.

The most common of them is osteoporosis, which, if diagnosed early, allows for a long life without motoric disability or other complications. Therefore, it is important to diagnose it early, at a stage in which it does not cause pathological fractures. Among a large number of possible screening tests, methods which are inert for the human body are the ultrasound examinations. However, as these tests show little accuracy, they should be supplemented, if there are any doubts, with the DEXA method, which uses low radiation energies. These methods have a negligible impact on the human body, and the benefits of their accuracy far outweigh the risks associated with X-rays [22,23].

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