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Biomineralizacja chrząstki panewki stawu biodrowego Biomineralization of hip joint socket (acetabulum) cartilage

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ABASTRACT

Processes that destroy the articular cartilage, including the cartilage of the hip joint, lead to joint dysfunction and, in extreme cases, to its immobilization. This necessitates total hip arthroplasty. Most researchers (1-27) focus on phenomena involving the cartilage of the femoral head. This article presents the results of research on biomineralization of the acetabulum.

Biomineralogical examinations of the acetabular cartilage were carried out and a gradual development of the cartilage mineralization was diagnosed. The comparative material was non-mineralized cartilage. It was determined that in various stages of mineralization, the content of elements in this cartilage – including Ca, P, Si, Na, and others – increases. In the early stages of mineralization, the cartilage appears macroscopically normal and non-mineralized. In the stages of advanced mineralization, the cartilage is hard, loses its slipperiness and elasticity. It often contains mineral micrograins (calcium phosphates). At this stage, the surface and structure of the cartilage become deformed, leading to joint dysfunction and the necessity to implant an endoprosthesis. Research indicates that the areas of cartilage biomineralization are the centres of its destruction caused by various factors (mechanical, genetic, inflammation, etc.). In the places of cartilage (collagen) damage, electrically charged biomineralization centres are formed, which "capture" nearby electrically charged ions, initiating cartilage biomineralization. In the tested samples, no relationship was observed between the degree of biomineralization of the cartilage in question and the age of the patients. It appears that an effective way to prevent the described phenomenon may be the blocking of cartilage biomineralization centres with the use of appropriate blockers. Development of such blockers requires separate research. This can prevent joint dysfunction and the need for endoprostheses.

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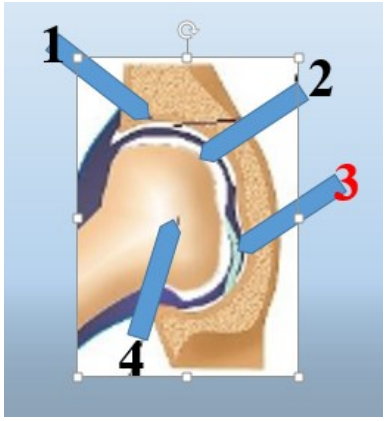
Introduction

Changes in the articular cartilage of the hip joint are the main cause of hip dysfunction (Photo 1A), which leads to the need for total joint arthroplasty and implantation of its prosthesis.

Many samples were used for testing, of which 6 (Tab. 1) were presented in this publication (Photo 2). Sample no. 1 was unchanged, not biomineralized cartilage (comparative material).



A

Samples of tested cartilage			
sample no	left/ right hip	age	sex
1	L	58	M
2	R	78	W
3	R	65	W
4	L	72	W
5	R	67	M
6	L	67	W

B

Photo 1. A – diagram of the hip joint. 1 – pelvic bone, 2 – cartilage covering the head of the femur, 3 – cartilage covering the acetabulum of the hip joint, 4 – the head of the femur. B – table with a list of femoral acetabular cartilage samples to be tested.

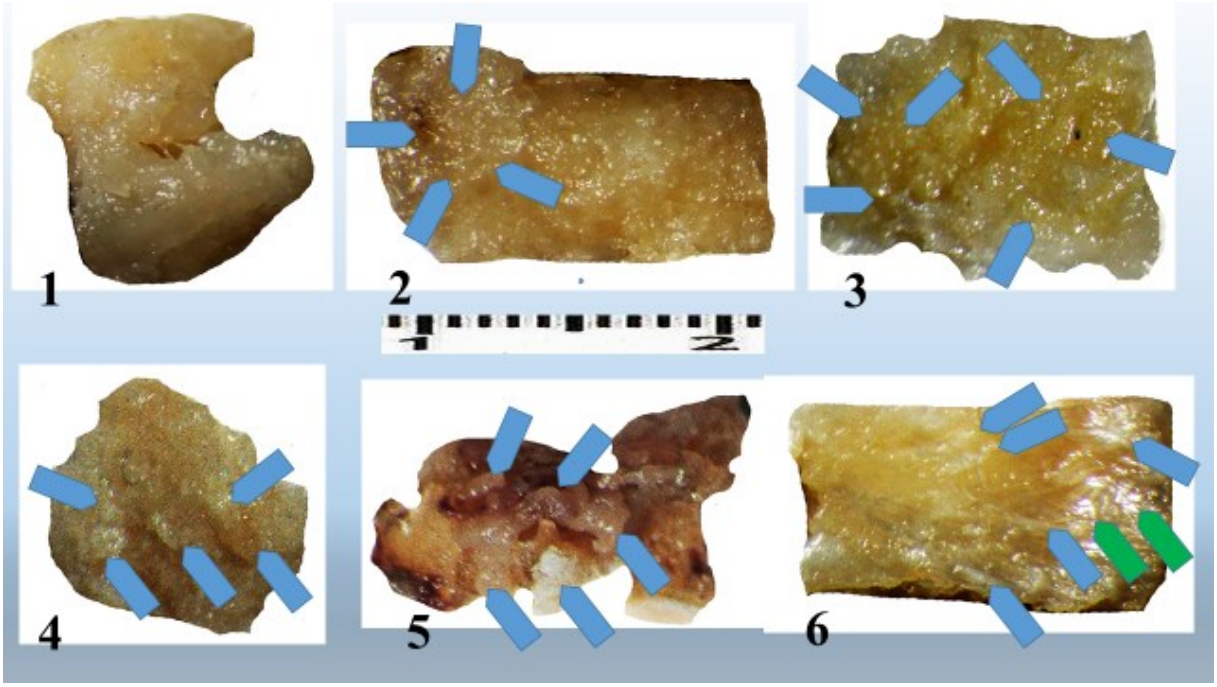


Photo 2. Macroscopic image of cartilage to be tested. 1 – non-mineralized cartilage (comparative material). 2, 3 – cartilage in the initial stage of mineralization (arrows show places with increased content of elements. 4-5 – cartilage affected by mineralization in the form of phosphate micrograins (arrows), leading to nodular cartilage deformation. 6 – zone mineralization of cartilage. Streaks of mineral concentrations occur in the cartilage (arrows).

Test methods

A scanning microscope (Jeol 540) with a chemical analyser (EDS) was used in the research. Observations of the cartilage surface, as well as chemical analyses of the surface (distribution of elements), energy spectra (EDS) and quantitative spot analyses were performed.
The results were presented in the form of photomicrographs, graphs (spectra) and tabular summaries.

Reference sample no. 1 (not subject to biomineralization)
The surface distributions of the analysed elements indicate (Photo 3) that there is no concentration of them in this cartilage. Thus, the research was limited only to the examination of the distribution of elements.

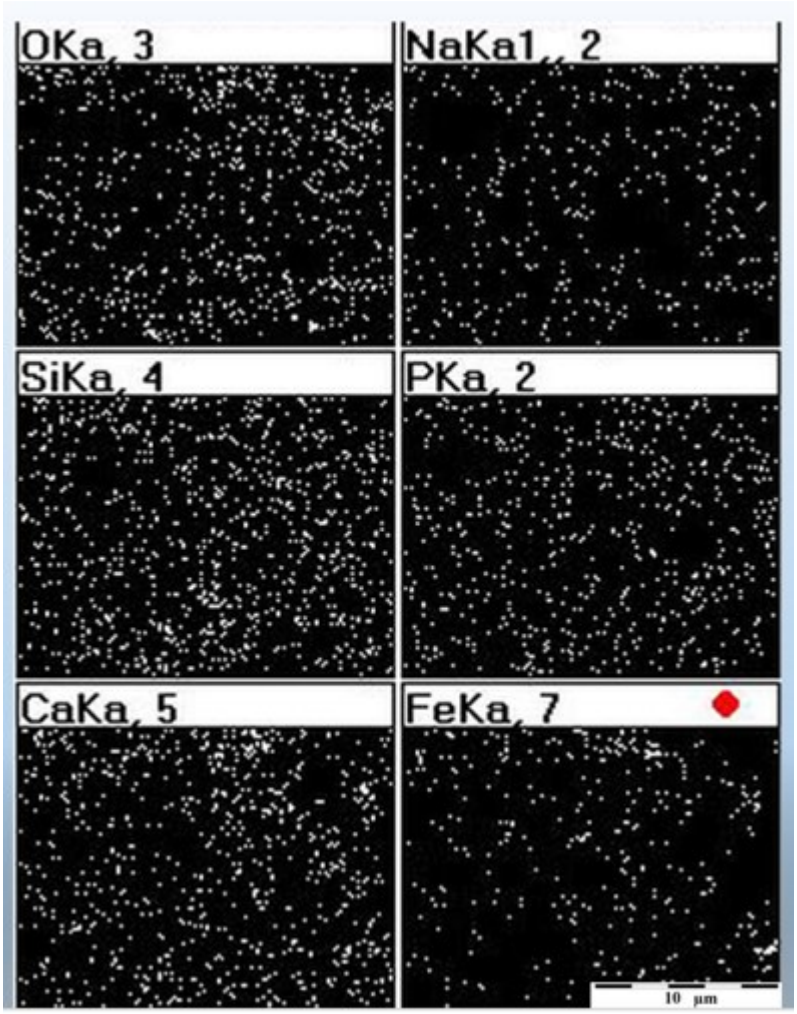


Photo 3. Maps of the distribution of elements in reference sample no. 1. Electron microprobe.

Sample no. 2
The cartilage showed surface deformations in macroscopic and scanning microscope observations, which in some places led to the formation of plate-like structures (Photo 4).

Chemical analyses of the surface of the cartilage revealed the presence of small areas where the amount of the tested elements was concentrated (Photo 5). This was confirmed by spot analyses of the cartilage, performed in the areas of such concentrations.

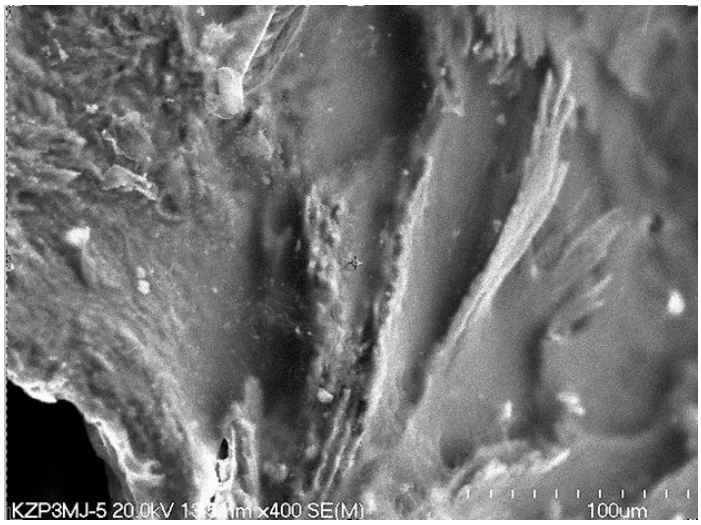


Photo 4. Sample no. 2. Damaged part of the acetabular cartilage with a lamellar structure, affected by the initial stage of biomineralization. SEM. Magnification by scale.

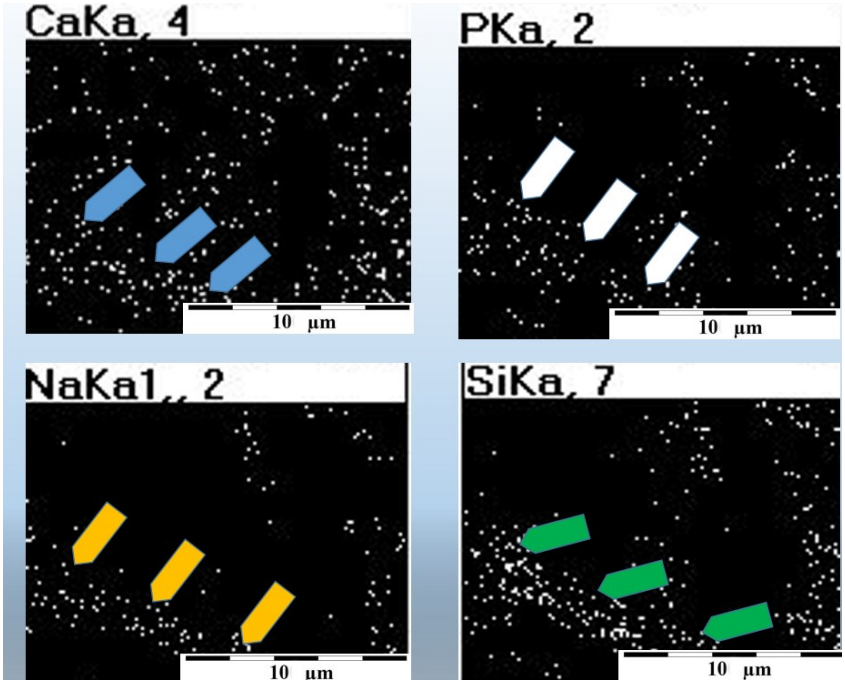
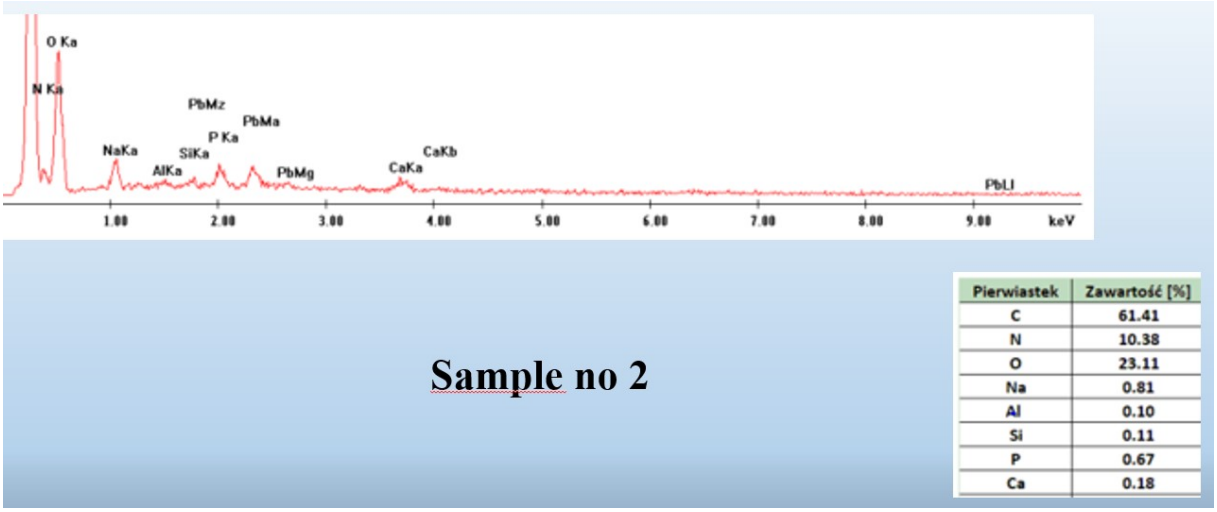


Photo 5. Sample no. 2. Early stage of biomineralization of cartilage. Concentrations of elements showed by arrows. Electron microanalyses.



Pierwiastek	Zawartość [%]
C	61.41
N	10.38
O	23.11
Na	0.81
Al	0.10
Si	0.11
P	0.67
Ca	0.18

Fig. 1. Sample no. 2. EDS spectrum of cartilage in an early stage of mineralization. Table 1 documents presence of elements in cartilage.

Presentation of the results of samples no. 3 and 4 was omitted due to their test results being similar as in the case of sample no. 2. In this way, the length of the article was reduced.

Sample no. 5

Biomineralization observed in this sample represents the next, more advanced stage of this process. The cartilage has a highly diversified surface, with areas of higher concentrations of elements than in the previously described cartilages – samples no. 3 and 4 (Photo 6).

Individual grains and spheres of phosphates found in this cartilage (Fig. 7A) can be "torn out" during joint motions, as shown in microscopic observations. After getting into the "working" space between the cartilage of the femoral head and the acetabulum of the hip joint, such grains can mechanically damage their surface.

Such areas of mechanical damage in the cartilage undoubtedly form further places of its biomineralization.

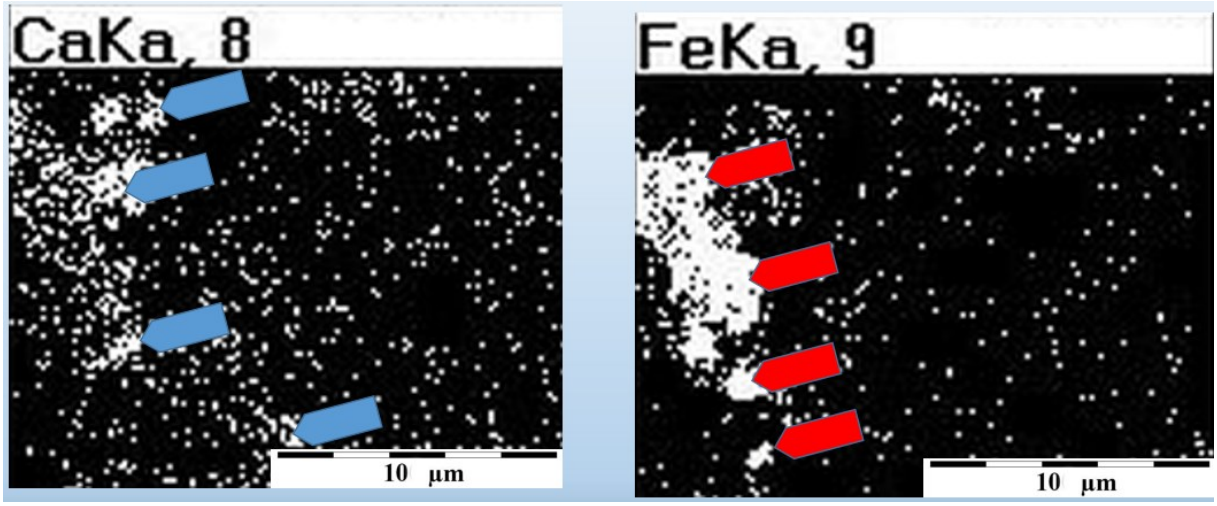
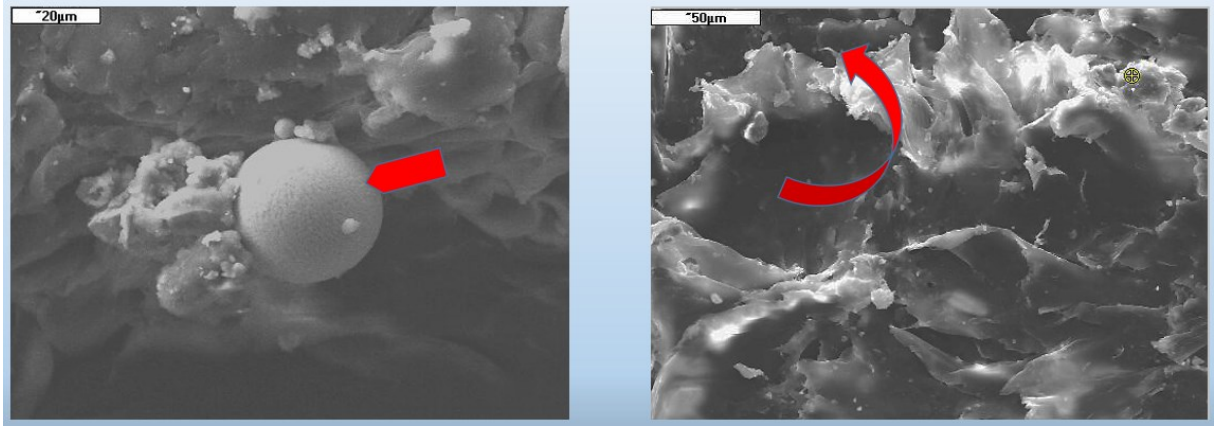


Photo 6. Sample no. 5. Concentrations of calcium and iron in mineral grains in cartilage affected by mineralization, leading to "plushing" of its surface. Electron microprobe.



A **B**

Photo 7. Sample no. 5. A – a grain of calcium phosphate (arrow) in the surface cartilage zone of the acetabulum. B – the arrow shows the spot where a grain was torn out of the cartilage. Scanning microscope.

Sample no. 6

The surface of this cartilage is pseudofibrous and represents another type of surface deformation (Photo 2, 6). Scanning examinations have shown that the elements mineralizing these pseudofibres are arranged linearly. Their increased numbers are located in the spaces between the fibres. In addition to elevated levels of calcium and phosphorus (Fig. 2), this type of acetabular cartilage deformation also shows increased amounts of silicon and iron (Photo 8).

Microscopically recognized grains have variable shapes (Photo 9 A). In addition to phosphate grains, mixed mineral-organic grains were found in this type of deformed cartilage (Photo 9 B). They are made of phosphates and possibly fats. Precise determination of the organic component is difficult due to their small size.

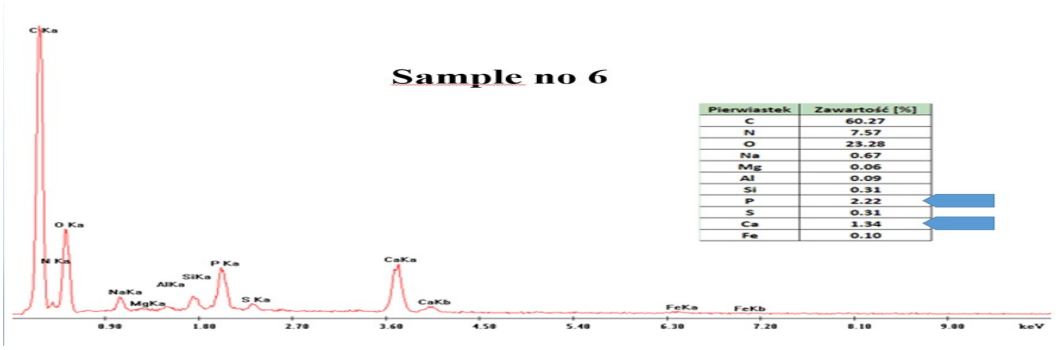


Fig. 2. Sample no. 6. EDS spectrum of cartilage in a more advanced stage of mineralization. Table documents presence of elements in cartilage. Arrows indicate elevated content of elements.

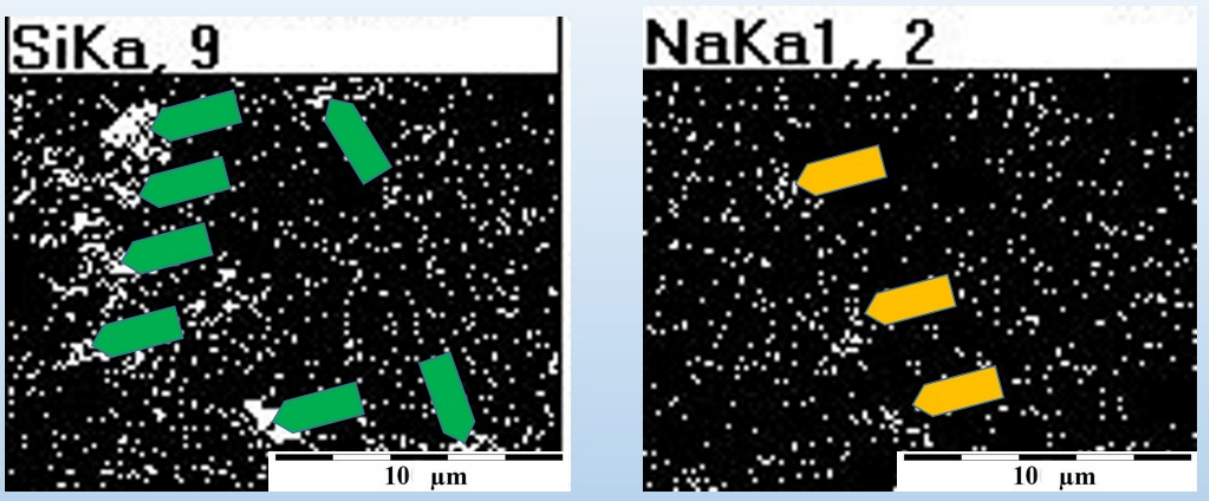
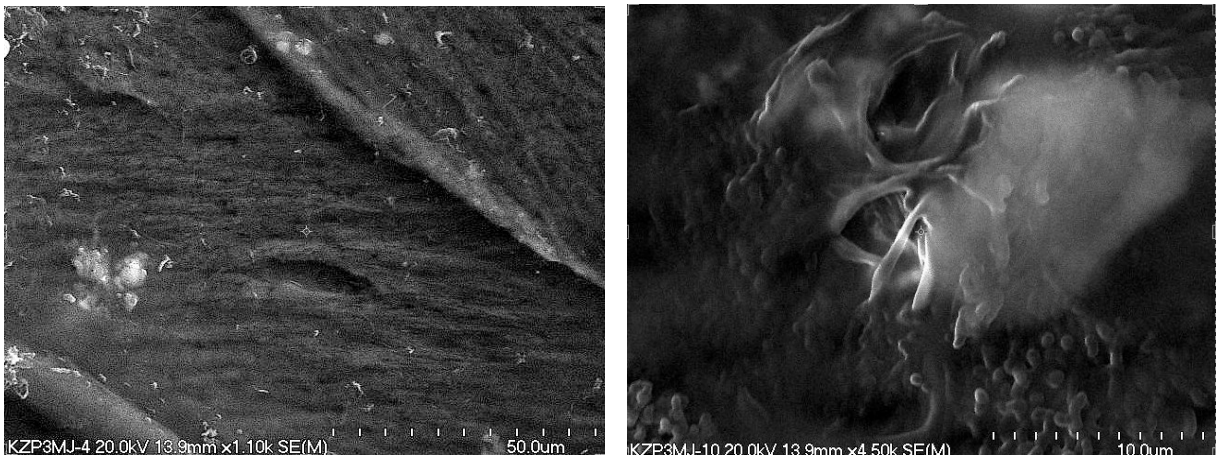


Photo 8. Sample no. 6. "Linear" distribution of Fe and Na in the surface layer of pseudofibrous acetabular cartilage. Electron microprobe.



A B

Photo 9. Sample no. 6. A – damaged surface of the acetabular cartilage with a clearly visible fibrous structure. The arrow shows concentrations of calcium phosphate. SEM. Magnification by scale. B – mixed mineral-organic grain (blue arrow) embedded within the surface of affected acetabular cartilage (yellow arrow). SEM. Magnification by scale.

Research summary

Performed studies suggest a gradual development of biomineralization of the acetabular cartilage (Fig. 3, 4). It develops in places where the atomic structure of the cartilage, mainly of collagen that builds it, is damaged. This damage can have different genesis: Genetic – when structural defects are transferred genetically. Mechanical defects – when damage to the cartilage is a result of physical stress on the joint and cartilage. Various infections, when infecting organisms produce toxins that destroy cartilage structures in their life processes, which in turn leads to the creation of biomineralization centers. Contamination of environment, food and water, etc. Each of these factors may function separately, but there is a possibility that they combine and interact with each other. The result is occurrence of the described phenomena in people of different ages.

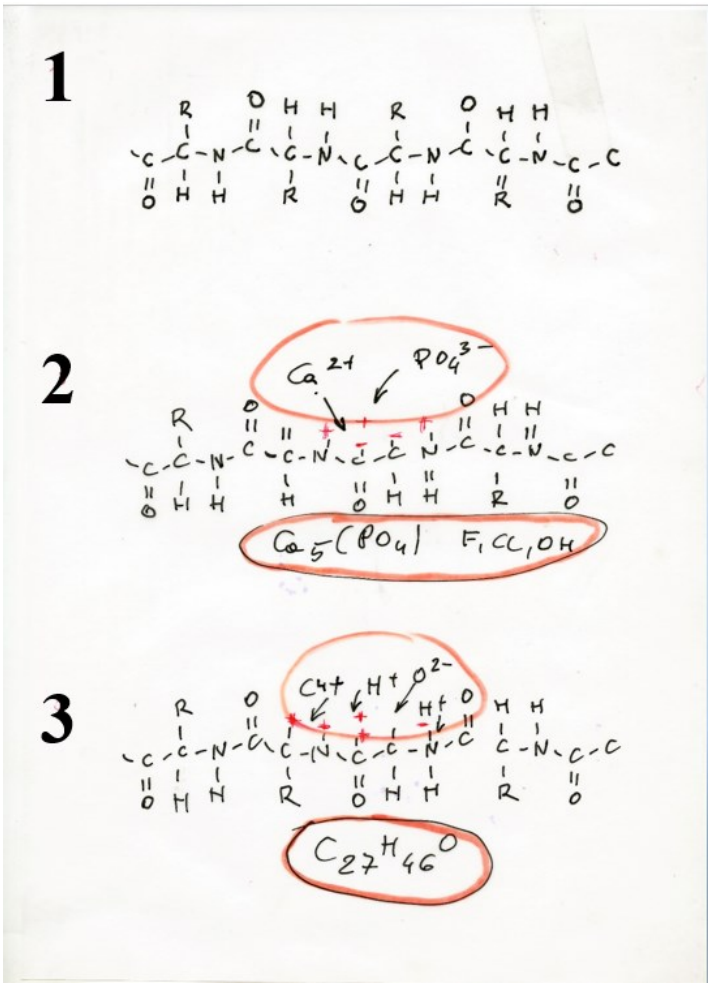


Fig. 3. Schematics of progression of biomineralization in the studied cartilage. 1 – Non-biomineralized structure of cartilage. 2 – Early stage of biomineralization of cartilage. Destruction of collagen fibres and formation of biomineralization centres. "Capturing" cations and anions in the places where the atomic structure of collagen is damaged, and incorporating elements into its structure. 3 –Formation of mineral grains in the cartilage.

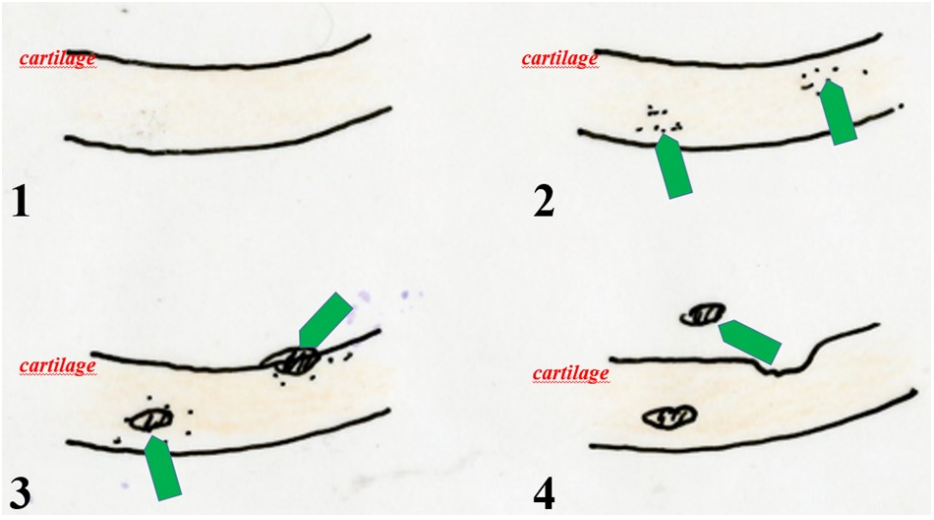


Fig. 4. Macroscopic picture of stages of cartilage biomineralization (cross-sections). 1 – non-mineralized cartilage. 2 – early stage of biomineralization – arrows (not visible macroscopically). 3 – continuation of biomineralization (arrows) and formation of mineral grains in cartilage. 4 – deformation of cartilage and possible extraction of mineral grains (arrow) into the "working space" of the joint.

Hip arthroplasty is a method that allows the joint and the patient to function properly. Blockers of biomineralization centres may be a future prophylactic method of combating joint dysfunction. Applied properly, they should stop the process of biomineralization of joint cartilage and prevent joint dysfunction.

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