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Clinical case of using tricalcium phosphate-based bone cement reinforced with hydroxyapatite

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The study and implementation of biomaterials for reconstructive orthopedic interventions remain a key focus of modern biomaterials science. Calcium phosphate ceramics are notable for their high biocompatibility, osteoconductive properties, and biodegradability. Developing materials capable of adapting to the shape of bone defects is particularly relevant. Objective. To evaluate the effectiveness of a metastable tricalcium phosphate cement reinforced with needle-shaped hydroxyapatite crystals for filling cavity defects in the acetabulum during total hip arthroplasty. Methods. A clinical case of a 52-year-old patient with stage IV coxarthrosis and acetabular cystic defects is presented. Following marginal cyst resection, the cement was applied to the cavity prior to implantation of an uncemented acetabular cup. Postoperative follow-up was performed on days 7 and 30 using radiography and multislice CT. Results. The postoperative course was uneventful. On day 7, the cavity was fully filled with cement; by day 30, multiple bone trabeculae had formed within the material, with density similar to native bone. Prosthesis fixation remained stable, without cement migration or aseptic demarcation. Conclusions. The use of calcium phosphate cement with a paste-like consistency reinforced with needle-shaped hydroxyapatite crystals allows complete defect filling, promotes bone-cement complex formation, and provides stable prosthesis fixation in the early postoperative period. Further studies with longer follow-up are required to assess long-term outcomes and material resorption.

Дослідження біоматеріалів для реконструктивно-відновних втручань в ортопедії залишається актуальним напрямом сучасного біоматеріалознавства. Особливу увагу привертають кальцій-фосфатні кераміки, які мають високу біосумісність, остеокондуктивні властивості та здатність до біодеградації. Актуальною є розробка матеріалів, здатних адаптуватися до форми порожнинних дефектів кісток. Мета. Оцінити ефективність метастабільного цементу на основі трикальційфосфату, посиленого голчастими кристалами гідроксилапатиту, для заповнення порожнинних дефектів кульшової западини під час тотального ендопротезування. Методи. Наведено клінічний приклад 52-річного пацієнта з коксартрозом IV ст. і кістами, локалізованими в кульшовій западині. Після пристінкової резекції кіст цемент пломбували в порожнину перед установкою безцементної чашки ендопротеза. Динамічне спостереження проводили на 7-му та 30-ту добу післяопераційного періоду зі застосуванням рентгенографії та МСКТ. Результати. Післяопераційний період проходив без ускладнень. На 7-му добу порожнина була заповнена цементом, на 30-ту добу візуалізували численні кісткові балки, що проростали в матеріал, із щільністю, подібною до кісткової тканини. Фіксація ендопротеза залишалася стабільною, ознак міграції цементу чи асептичного розмежування не зафіксовано. Висновки. Використання кальцій-фосфатного цементу з пастоподібною консистенцією та голчастими кристалами гідроксилапатиту забезпечує повноцінне заповнення дефекту, сприяє формуванню кістково-цементного комплексу та створює умови для стабільної фіксації компонентів ендопротеза в ранньому післяопераційному періоді. Подальші дослідження з триваліишим спостереженням дозволять оцінити віддалені результати та резорбцію матеріалу. Ключові слова. Кульшовий суглоб, дефекти кісткової тканини, кістковий цемент.

Keywords. Hip joint, bone defects, bone cement

Introduction

The study and implementation of biomaterials for reconstructive and restorative interventions in the field of orthopedics remains one of the key directions of modern biomaterials science [1, 2]. Special attention is drawn to calcium phosphate ceramics, which are characterized by high biocompatibility, chemical affinity with bone tissue, biodegradability, and pronounced osteoconductive and osteointegrative properties. Given the variety of configurations and sizes of cavitary bone defects that occur as a result of disease or surgery, the search for materials capable of adapting to the shape of the formed defect is highly relevant [3, 4]. At the same time, the optimal composition of ceramic materials that would ensure necessary mechanical properties without compromising their bioresorbable characteristics has yet to be determined. This paper presents a clinical case of using a calcium-phosphate biomaterial developed at the Department of Physics, Karazin Kharkiv National University [5], for filling a cavitary defect of the acetabulum during hip joint arthroplasty. The clinical testing followed thorough experimental studies on rats, the results of which indicate the promising application of this biomaterial in orthopedic practice [26].

Purpose: To investigate the possibility of using metastable cement based on tricalcium phosphate, reinforced with hydroxyapatite needles, as a material for filling cavitary defects in bone tissue.

Materials and methods

The study was approved by the local bioethics committee (protocol of the meeting at the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine, dated 03.08.2023, No. 234).

A 52-year-old male patient, referred to as Patient V., presented with pain, discomfort during walking and at rest, limping, and restricted range of motion in the hip joint. The patient had been suffering for at least 5 years, having undergone conservative treatment with short-term improvements. The pain syndrome exacerbated 2–3 times a year. Clinical and radiological examination revealed signs of stage IV coxarthrosis. A massive cyst was detected on the upper-anterior wall of the acetabulum (Figure 1). No related pathological changes were detected.

In targeted radiographs of the right hip joint in both the anteroposterior and lateral projections, subchondral changes were observed, mainly on the roof of the acetabulum and the upper part of the femoral head. Bone resorption was noted in the subchondral zone (the maximum diameter of the cyst in the acetabular roof area was up to 13 mm, and in the femoral head up to 8 mm; at some levels, the endplate bone was significantly thinned). Radiographic signs of right-sided coxarthrosis stage IV with pronounced cyst-like bone remodeling were diagnosed.

A total hip arthroplasty surgery using a cementless construct was planned. The identified bone tissue defects could potentially affect the secondary stability of the acetabular cup of the prosthesis, which occurs through the ingrowth of bone trabeculae into the pores of the outer surface. To achieve full secondary stability of the cup, it was decided to perform a wall resection of the cyst on the upper-anterior wall of the acetabulum and to replace the formed defect.

For the defect replacement, synthetic calcium-phosphate bioceramics — hydroxyapatite (HA $Ca_{10}(PO_4)_6(OH)_2$) and tricalcium phosphate (TCP $Ca_3(PO_4)_2$) — were selected for their safety and efficacy [7]. The bone cement based on TCP was reinforced with needle-like crystals of HA.

The study of the dependency of the changes in compressive strength of the cement on the amount of needle-like hydroxyapatite crystals revealed that the strength increases proportionally with the number of these crystals. At 4 % weight/weight, it reaches the maximum values with an average of 5.5 MPa [25]. The full setting time of the calcium phosphate cement (CPC) usually takes several tens of minutes. A 2.5 % sodium hydrogen phosphate (Na2HPO4) solution was used as the liquid phase for preparing the cement, which was added to the portion of the α′-TCP powder, ensuring a solid/liquid phase ratio of 1/1.25. Just before use, 4 % weight/weight of needle-like hydroxyapatite crystals were added to the liquid phase. These crystals were obtained by hydrothermal synthesis

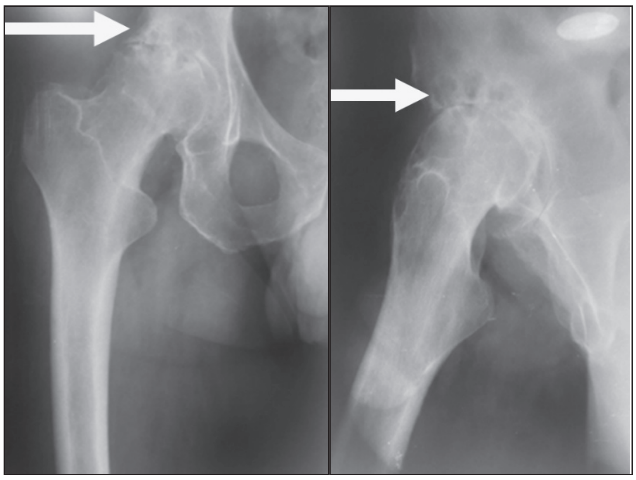

Fig. 1. X-ray images of the right hip joint (noting cysts in the acetabulum)

using an original technology (T = 235 °C, P = 20 atm, t = 1 hour) [8].

The mass was then carefully mixed with a spatula until a homogeneous paste was obtained, and it was allowed to rest for 3–5 minutes [5]. Two minutes after the mixing started, a paste-like consistency formed, which gradually hardened and took shape over time. The resulting paste was used to fill the bone defect, compacting each new portion with a spatula until the defect was fully filled.

After preparing the acetabulum with reamers to the required size, the cyst on the upper-anterior wall was visualized (Figure 2). Using a curette, the wall resection was performed, creating a cavity of dimensions 2×2.5×3 cm. After careful hemostasis, a portion of cement was prepared sufficient to fill the defect: 15 grams of cement and the corresponding amount of liquid, reinforced with HA needles, were used. After the bone cavity was filled with cement, the acetabular cup and other components of the prosthesis were installed.

Results and discussion

No complications were observed in the postoperative period. The patient was examined on the 7th and 30th day after the surgery.

Medications in the postoperative period followed the standard protocol for primary hip arthroplasty patients: prevention of thromboembolic complications and antibiotic therapy for infection prevention. The first three days of dressing changes were performed daily. On the second day, the drain was removed. The postoperative wound healed with primary tension. The patient's mobilization followed a standard process: the patient was taught to walk

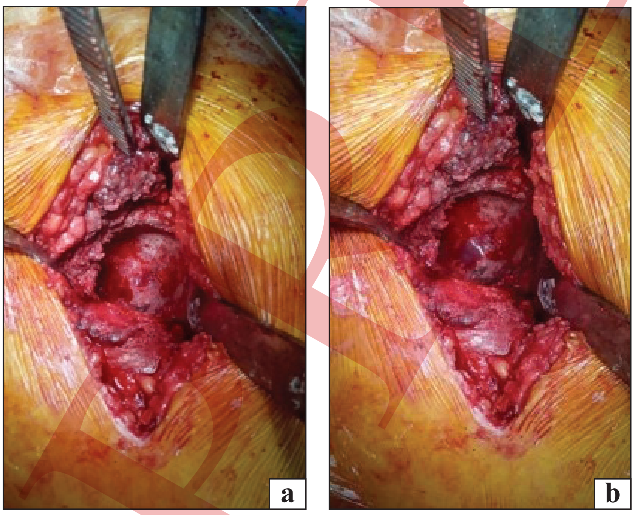

Fig. 2. Intraoperative photo. Cyst in the upper wall of the acetabulum: a) before and b) after the filling

the day after surgery with a controlled load (40 % of body weight), using crutches as additional support. Therapeutic exercises targeting the lower limb musculature were prescribed, and a structured postoperative rehabilitation program was conducted under the supervision of a rehabilitation specialist.

7th day post-surgery. Radiographic signs of the state after right hip joint arthroplasty were observed. The cyst in the lateral part of the subchondral zone of the acetabular roof was filled with a plastic material (calcium phosphate cement) (Figure 3).

30th day post-surgery: Bone growth along the edge of the acetabulum was noted, extending up to 8 mm, with some sclerosis in the subchondral zone. In this region, a single cyst with a diameter of 13 mm was found, filled with material in which numerous bone trabeculae were identified, with density identical to that of bone tissue (Figure 4).

Compared to the radiographic images taken on the 7th day after surgery, many bone trabeculae were observed between the acetabular endplate and the outer surface of the prosthetic acetabular cup.

Additionally, a multi-slice computed tomography (MSCT) scan of the right hip joint was performed on the 30th day (Figure 5). The results indicated that bone growth had formed along the edge of the acetabulum, extending up to 9 mm. The subchondral zone in this area was unevenly sclerosed, and the cyst was filled with a dense material (likely cement). In one of the cysts, between its walls and the substance, numerous bone trabeculae could be traced, which blurred the boundary between the bone and the material [9].

The clinical and radiological data obtained confirm the appropriateness and potential of using calcium phosphate cement based on TCP, reinforced with needle-like HA crystals, to fill cavitary defects in the acetabulum during total hip arthroplasty. The distinctive feature of this clinical case is the presence of a significant irregularly shaped defect in the acetabular roof zone, which could potentially affect the secondary stability of the uncemented acetabular cup.

The use of calcium phosphate cement with a paste-like consistency enabled the complete filling of the complex-shaped defect and ensured a tight contact between the material and the walls of the bone cavity. This created favorable conditions for the further ingrowth of bone trabeculae into the implanted material. The radiological and MSCT signs observed on the 30th postoperative day, indicating the formation of bone trabeculae in the cemented area, are consistent with experimental data on the bioresorption

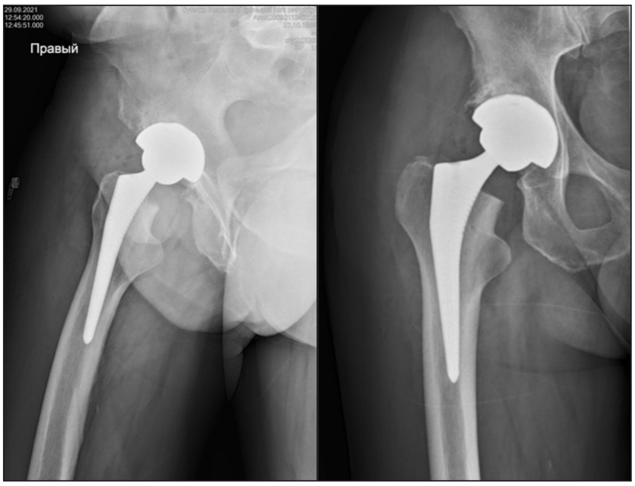

Fig. 3. X-ray images of the joint on the 7th day after hip replacement surgery and bone defect reconstruction

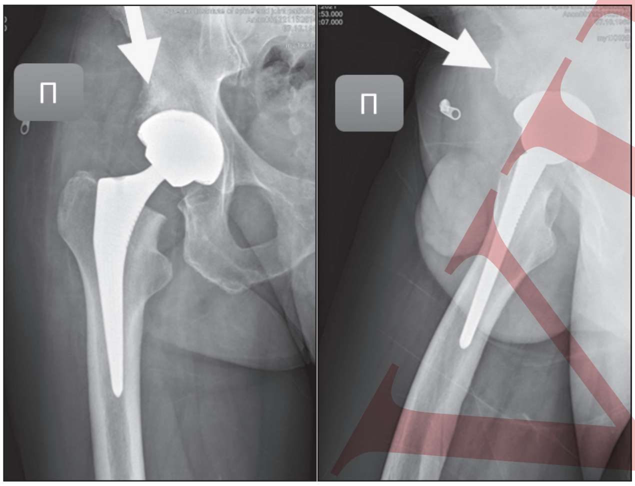

Fig. 4. X-ray images of the right hip joint on the 30th day after hip replacement surgery and bone defect reconstruction

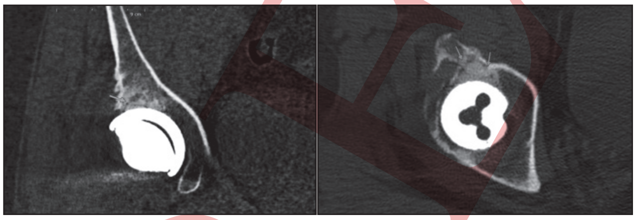

Fig. 5. Multi-slice computed tomography of the right hip joint

and osteointegration of materials based on TCP and HA [10].

The reinforcement of the cement with needle-like HA crystals at a concentration of 4 % w/w allowed for an increase in its compressive strength to a level sufficient for use in load-bearing zones, without compromising the biological activity of the material. The balance between mechanical stability and controlled resorption is known to be a critical factor for the successful reconstruction of bone defects in the hip joint region [11–14]. In the presented clinical case, no signs of cement migration, formation of an aseptic boundary zone, or disruption of prosthesis fixation were observed in the early postoperative period.

The results obtained also indicate that the use of this biomaterial may improve the conditions for secondary stability of the prosthetic cup by restoring the integrity of the subchondral bone and forming a bone-cement complex capable of gradual remodeling [15–16]. Further studies with a larger number of clinical observations and a longer period of dynamic monitoring will allow for a more objective assessment of the long-term effectiveness, resorption rates, and the impact of the reinforced calcium phosphate cement on the survivability of the hip prosthesis components.

Conclusion

Postoperative radiological and MSCT data indicate positive dynamics in the replacement of the cavitary bone defect with bone cement based on tricalcium phosphate, reinforced with needle-like hydroxyapatite crystals, showing signs of osteointegration. The paste-like consistency, osteoconductive and biocompatible properties of the cement ensured full filling of the defect with a complex configuration and created conditions for the stable fixation of the prosthesis components in the early postoperative period. The limited follow-up period did not allow for the assessment of long-term results, thus emphasizing the need for further clinical research.

Conflict of interest. The authors declare no conflict of interest.

Prospects for further research. Optimization of surgical outcomes in patients with cavitary bone defects.

Authors' contribution. Filipenko V. A. — performing the surgical intervention, setting the goals and objectives of the study, editing the article; Ivanchuk K. S. — analysis of primary material, conducting experimental research, drafting the article.

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CLINICAL CASE OF USING TRICALCIUM PHOSPHATE-BASED BONE CEMENT REINFORCED WITH HYDROXYAPATITE

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