Original article
https://doi.org/10.18019/1028-4427-2024-30-6-831-844

Results of minimally invasive core decompression and autologous bone grafting in combination with autologous bone marrow aspirate concentrate in the treatment of patients with aseptic osteonecrosis of the femoral head

D.A. Naida[1], B.V. Tyulkevich[1], D.A. Malanin[2], V.V. Kondrashenko[2]✉, M.V. Demeshchenko[2], N.N. Chirkov[3]

[1] Burdenko Main Military Clinical Hospital, Moscow, Russian Federation
[2] Volgograd State Medical University, Volgograd, Russian Federation
[3] Federal Center for Traumatology, Orthopaedics and Joint Arthroplasty, Cheboksary, Russian Federation

Corresponding author: Vladimir V. Kondrashenko, vovamail2009@yandex.ru

Abstract

Introduction Currently, limb salvage methods have been used for the treatment of aseptic osteonecrosis of the femoral head (ANFH), but their use does not always avoid joint replacement in the later stages of the disease. The combination of core decompression and autologous bone grafting with autologous bone marrow aspirate concentrate (BMAC) in the treatment of patients with ANFH could improve their quality of life, delay joint replacement, or, in some cases, avoid it completely.

Purpose To evaluate the results of surgical treatment of patients with ANFH using minimally invasive core decompression and autologous bone grafting in combination with BMAC, develop an algorithm for choosing a method of surgical treatment based on the extent of damage to the femoral head and the stage of the disease.

Material and methods A pilot multicenter study included 86 patients diagnosed with ANFH. All patients underwent minimally invasive core decompression in combination with autologous bone grafting and BMAC. Results were analyzed 3, 6, 12 months after surgery.

Discussion Due to the fact that the presented study included mainly patients with post-Covid and steroid-induced osteonecrosis, and did not include patients with the first stage of the disease, the percentage of positive treatment results was slightly lower compared to other similar studies.

Results Within 3 to 6 months after surgery, 21 patients (24 %) required joint replacement; among the remaining 65 patients (76 %), there was a significant improvement in the condition and quality of life that was confirmed by instrumental studies and functional assessment.

Conclusion The technique of minimally invasive core decompression and autologous bone grafting in combination with BMAC is an effective method of treatment patients with pre-collapse ANFH stages, might improve their quality of life but does not allow regression of structural changes in the bone.

Keywords: osteonecrosis, femoral head, core decompression, bone grafting, bone marrow aspirate concentrate

For citation: Naida DA, Tyulkevich BV, Malanin DA, Kondrashenko VV, Demeshchenko MV, Chirkov NN. Results of minimally invasive core decompression and autologous bone grafting in combination with autologous bone marrow aspirate concentrate in the treatment of patients with aseptic osteonecrosis of the femoral head. *Genij Ortopedii*. 2024;30(6):831-844. doi: 10.18019/1028-4427-2024-30-6-831-844

INTRODUCTION

Aseptic osteonecrosis is a multifactorial degenerative disease characterized by impaired microcirculation in a certain bone tissue area, leading to the death of osteocytes, demineralization, resorption, as well as changes in the trabecular architecture of the bone resulting in secondary osteoarthritis of the adjacent joint [1, 2].

In general, to date there is no single epidemiological report on the incidence of this pathology among the general population. However, in a number of countries, screening is periodically carried out to identify and assess the prevalence of the above-mentioned disease in the population. According to statistics, in the USA, from 300 thousand to 600 thousand cases are affected by aseptic necrosis of the femoral head (ANFH) in the general population. From 10 thousand to 20 thousand new cases of the disease are registered annually. These numbers correlate with the results of studies conducted in other countries. Thus, a screening analysis of the Japanese population showed an incidence rate of 1.9 per 100 thousand, and in the UK from 1.4 to 3.0 per 100 thousand. It is worth noting that the majority of patients suffering from this pathology are young and working-age people who have high demands on joint function [3, 4, 5].

Currently, the pathogenesis of ANFH remains incompletely understood, but it has been established that one of the etiological factors of the disease is long-term use of glucocorticosteroids (GCS), which has become widespread during the COVID-19 pandemic. The use of GCS has become an effective method for treating moderate forms of the disease and for relieving acute respiratory syndrome, what has saved the lives of many patients [6, 7]. The high therapeutic potential of these drugs in relation to COVID-19 is explained by their ability to significantly suppress the expression of major pro-inflammatory mediators such as IL-1, IL-6, TNF-α, IFN-γ to hinder the development of a "cytokine storm" and help prevent acute respiratory distress syndrome [8, 9, 10]. However, it has been proven that long-term hormonal therapy leads to serious side effects, one of which is ANFH [11, 12, 13, 14].

Moreover, it is now reliably known that the new coronavirus infection may lead to the development of osteonecrosis even without the administration of GCS due to disseminated coagulopathy and occlusions of the small vascular bed [7, 11, 12].

Speaking about the ANFN pathogenesis, it is also necessary to note the ongoing structural changes in bone tissue that prevent its independent regeneration. The explanation lies in the a sclerotic plate formed by osteocytes during osteonecrosis, which separates the necrotic area from the healthy bone and hinders vascular invasion into the pathological focus, as a result of which its further revascularization becomes impossible [3, 15, 16, 17].

Since the 1960s, limb saving methods of treating ANFH have been widely used in orthopaedic practice, such as decompression of the necrotic lesion, vascularized and non-vascularized bone grafting [18, 19, 20]. These methods of surgical treatment are used at precollapse stages of osteonecrosis, but, unfortunately, they do not always achieve the desired result and could not postpone joint replacement for a long time or help avoid it [21, 22, 23, 24, 25].

In current traumatology and orthopaedics, studying the possibilities of orthobiological products is of great importance, one of which is autologous bone marrow apirate concentrate (BMAC). The high regenerative potential of mesenchymal stromal cells (MSCs) was appreciated by the French scientist P. Hernigou, who was the first to use BMAC for the treatment of aseptic osteonecrosis [26].

The hypothesis of our study was based on the idea of possible improvement of treatment results in patients with ANFH by combining a traditional surgical technique of necrotic lesion decompression and bone autografting with a modern BMAC orthobiological product [22, 27, 28, 29, 30].

The **purpose** of the work was to evaluate the results of surgical treatment of patients with ANFH by the method of minimally invasive decompression and bone autografting in combination with BMAC, as well as to develop an algorithm for choosing a surgical method based on the volume of the femoral head lesion and the stage of the disease.

MATERIALS AND METHODS

A pilot multicenter prospective non-randomized study was conducted from 2021 to 2023 at the Center for Traumatology and Orthopaedics of the Burdenko Main Military Clinical Hospital (Moscow), Volgograd State Medical University (Volgograd), and the Federal Center for Traumatology, Orthopфedics, and Joint Arthroplasty (Cheboksary).

The clinical study complied with the requirements set forth in the Declaration of Helsinki. The study was approved by the institutional ethics committee (registration number: IRB 00005839 IORG 0004900 (OHRP)). Patients voluntarily gave written informed consent to participate in the study and publish its results.

A total of 93 patients underwent treatment with the technique described. According to the inclusion and exclusion criteria, the study involved 86 patients diagnosed with ANFH: 64 men, 22 women in the average age of (40.1 ± 6.7) years, body mass index (28.2 ± 3.8), disease duration (6.2 ± 4.1) months. Unilateral process was observed in 23 patients and bilateral in 63; the volume of femoral head damage ranged from 15 to 60 %. A confirmed diagnosis of COVID-19 preceding the manifestation of pain was in 73 cases (84.9 %); 61 patients (70.9 %) underwent glucocorticosteroid therapy, the total dosage of which was (406 ± 28) mg in dexamethasone equivalent.

The diagnosis was established based on complaints, anamnesis and data from instrumental methods (X-rays, CT, MRI). MRI study detected signs of aseptic necrosis. On T2-weighted images, a perifocal zone of heterogeneous hyperintensive signal was visualized due to edema and bone marrow ischemia in the femoral head area. On T1-weighted images, the above-mentioned areas had a hypointensive signal and corresponded to an osteonecrotic lesion.

To assess the clinical and functional state of the hip joint and the results of treatment, the following evaluation systems were used: modified Harris Hip Score, Lequesne index (limitation of life activities), UCLA Activity Score, Eq-5d (quality of life questionnaire), visual analog scale for pain (VAS), subjective assessment of quality of life (0 to 100 %).

Inclusion criteria were:

— Association Research Circulation Osseuos (ARCO) ANFH stage 1–2;

— MRI findings of areas of trabecular edema in the femoral head area;

— Pain intensity not lower than 6 VAS points.

The study excluded patients over 60 years of age, HIV-infected patients, carriers of antigens to hepatitis B and C viruses, as well as individuals with blood and/or bone marrow diseases, with concomitant pathologies of internal organs in the decompensation stage, and subjects with a history of malignant oncological diseases. Also, the exclusion criteria were the presence of an acute inflammatory process; intra- and (or) peri-articular GCS injections, hyaluronic acid preparations or other orthobiological products within 6 months before the initial examination.

All patients underwent minimally invasive decompression and bone autografting of the femoral head in combination with ABMC.

The treatment results were interpreted 3, 6 and 12 months after the operation. At follow-ups, the dynamics of pathological changes were assessed studying MRI findings, determining the size of the osteonecrotic lesion and trabecular edema of the femoral head, its sphericity, as well as the presence of signs of secondary osteoarthritis.

The main criterion for failure in the treatment of this pathology was the need for hip arthroplasty in patients selected for the study. Moreover, the final result was considered poor if collapse of the articular surface of the femoral head or significant signs of secondary osteoarthritis based on radiological diagnostic methods were detected. Objectively, the outcome of the study was assessed as poor if HHS was 70 points and lower.

Statistical processing of the results was carried out using mathematical statistics methods, using the Excel 2019 for Windows.

Analysis of parameters with a normal distribution of values was carried out using the Student t-test. In turn, nonparametric quantitative features were analyzed using the Friedman criterion. The results obtained were compared with the tabular values at the selected level of statistical significance $p < 0.001$.

The research centers used different methods for obtaining BMAC. Clinics in Moscow and Cheboksary used the automated closed system Angel® System (Arthrex, USA). At the clinical base of the department of traumatology, orthopaedics and military field surgery in Volgograd, BMAC was obtained by centrifuging the aspirate in YCELLBIO tubes (Korea). In this regard, a preliminary laboratory study was conducted to select optimal centrifugation modes, determine the qualitative and quantitative characteristics of orthobiological products.

Evaluation of qualitative and quantitative characteristics of orthobiological products

Bone marrow aspirate from 22 patients was studied in the laboratories of the Burdenko Main Military Clinical Hospital, Volgograd State Medical University and Volgograd Medical Research Center. BMAC was obtained using the automated closed system Angel® System (Arthrex, USA) at a hematocrit of 15, as well as the centrifugation method in YCELLBIO tubes (Korea) at a speed of 2400 rpm for 10 min.

Flow cytometry and a cell analyzer were used to study the characteristics of the aspirate and supernatant. The samples were layered on Ficoll-Paque Plus (Sweden) with a density gradient of 1.077 g/ml, separated, and a fraction with "pure" mononuclear cells was isolated. Flow cytometry was used for immunophenotyping and determining the concentration of MSCs in the resulting sample, using antibodies to marker co-receptors: CD73, CD105, CD90. A cell analyzer was used to count the number of erythrocytes, platelets, leukocytes, and lymphocytes.

According to the data obtained, the above-mentioned methods provided the increase in the number of MSCs and platelets in the concentrate by 6–9 and 10–12 times, respectively, compared to native aspirate, and the orthobiological products obtained by automated means and by centrifugation in special test tubes had similar qualitative and quantitative characteristics.

Surgical technique

Collection of bone marrow aspirate After the surgical field had been treated and with the patient in the supine position on an orthopedic table (Fig. 1) under spinal anesthesia, the first step was to perforate the cortical layer in the area of the anterosuperior iliac wing spine using an 11G aspiration trocar. The tip of the aspirator was immersed in the bone with rotational movements to a depth of 2 to 7 cm. Next, using a syringe, an aspirate was collected in a volume of 90 to 160 ml (Fig. 2). Moreover, during bone marrow aspiration, the direction of the trocar tip in the thickness of the spongy bone changed in order to minimize the entry of the patient's peripheral blood into the syringe and achieve the maximum concentration of blast cells in the aspirate.

Fig. 1 Patient's position on the orthopaedic table

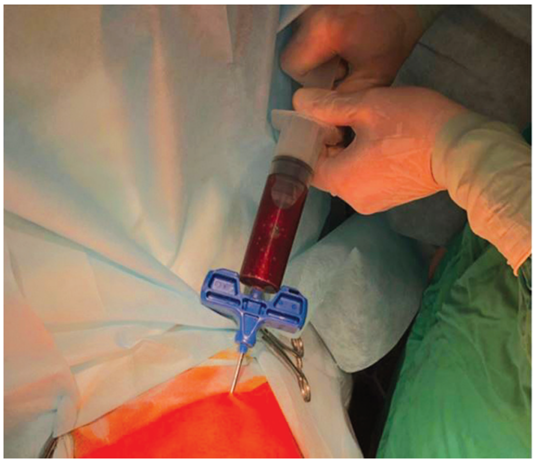

Fig. 2 Aspiration of bone marrow from the iliac crest

BMAC production In the clinics of the Burdenko Main Military Clinical Hospital and the Federal Center for Traumatology and Orthopaedics, bone marrow aspirate was placed in an automated closed system Angel® System (Arthrex, USA) together with 15 ml of anticoagulant (heparin 5000 U), then centrifuged with a hematocrit parameter of 15.

At the clinical base of the Volgograd State Medical University, bone marrow aspirate was distributed into YCELLBIO tubes (Korea) together with an anticoagulant (heparin 5000 U) at a ratio of 1.5 ml of anticoagulant per 13.5 ml of bone marrow aspirate in each tube, then they were centrifuged at 2400 rpm for 10 min according to the original method (RU Patent No. 2763250) [39]. After separation, the fraction with a high MSC content was centered in the narrow neck of the tube and extracted using a syringe (Fig. 3). Then, a bone autograft was collected from the iliac wing in a volume of about 18 cm^3, which was crushed into fragments using bone rongeurs and mixed with the previously produced BMAC (Fig. 4).

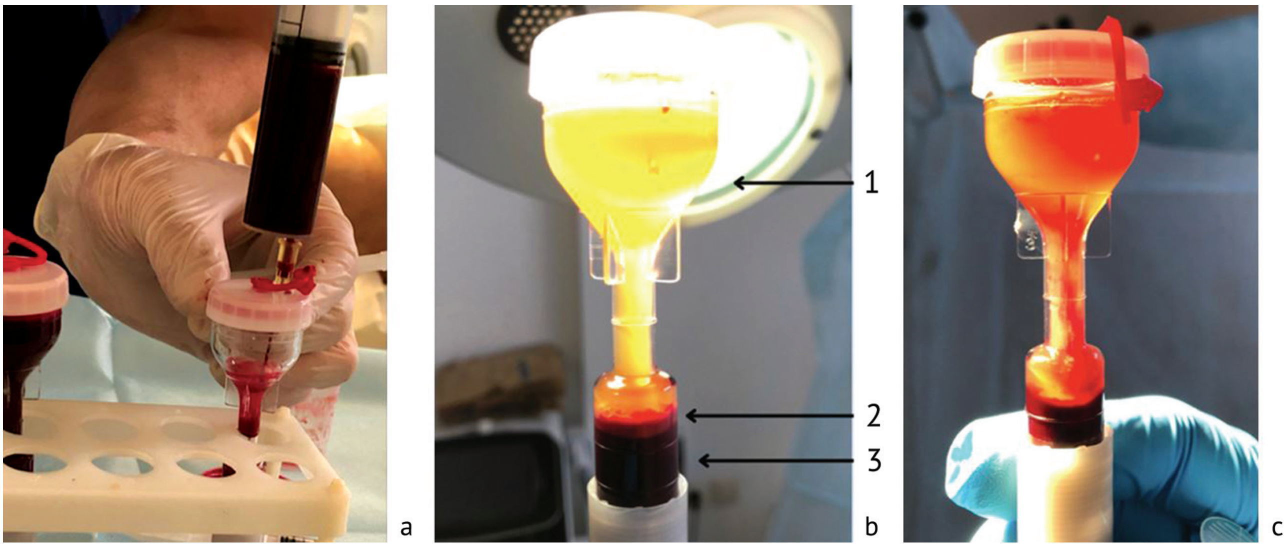

Fig. 3 Placing the aspirate into YCELLBIO tubes (*a*); separation into fractions (1 — plasma, 2 — fraction with a high content of MSCs, 3 — erythrocyte mass (*b*); centering the bone marrow concentrate in the neck of the tube by rotating the rotary cap (c)

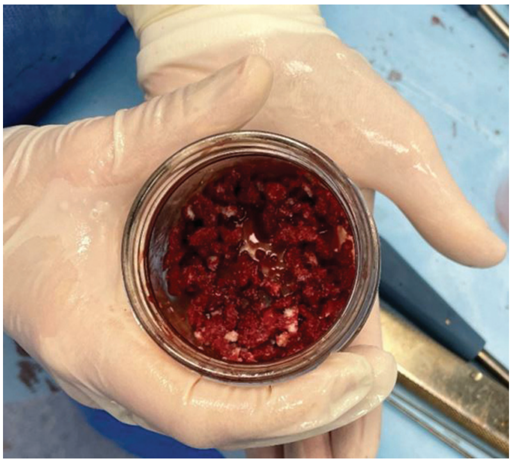

Fig. 4 Crushed autogenous bone mixed with BMAC

Decompression and autogenous bone grafting of osteonecrotic lesions Without changing the patient's position on the operating table, a 2.3-mm diameter Kirschner wire was percutaneously inserted along the lateral surface of the thigh, distal to the greater trochanter, into the center of the osteonecrotic lesion that localizes in the anterosuperior sector of the femoral head. The positioning of the guide wire was controlled with an image intensifier in the direct and axial projections.

At the site of wire insertion, a 2–3 cm long surgical approach was performed. Next, a 10-mm diameter cannulated drill was installed along the wire and drilling was performed along the femoral neck to the affected area, removing necrotic masses and surrounding areas of osteosclerosis as completely as possible (Fig. 5).

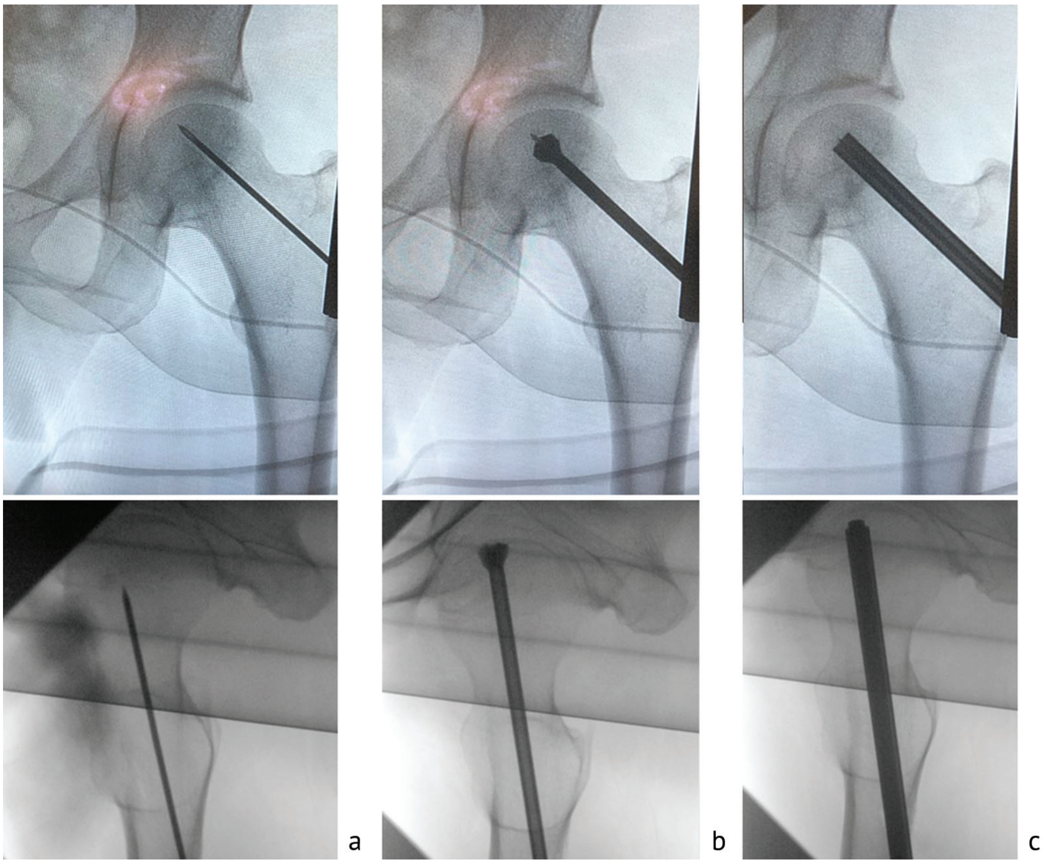

Fig. 5 Stages of bone grafting of the osteonecrotic focus in the femoral head: *a* insertion of a wire into the area of the necrotic focus; *b* reaming with a cannulated drill; *c* insertion of an instrument for bone grafting

After removing the drill, a hollow 9-mm diameter guide was inserted into the resulting canal. Next, under the EOP control, the crushed bone autograft, pre-mixed with BMAC, was impacted into the target zone of the femoral head by doses (Fig. 6). The wound was sutured layer by layer.

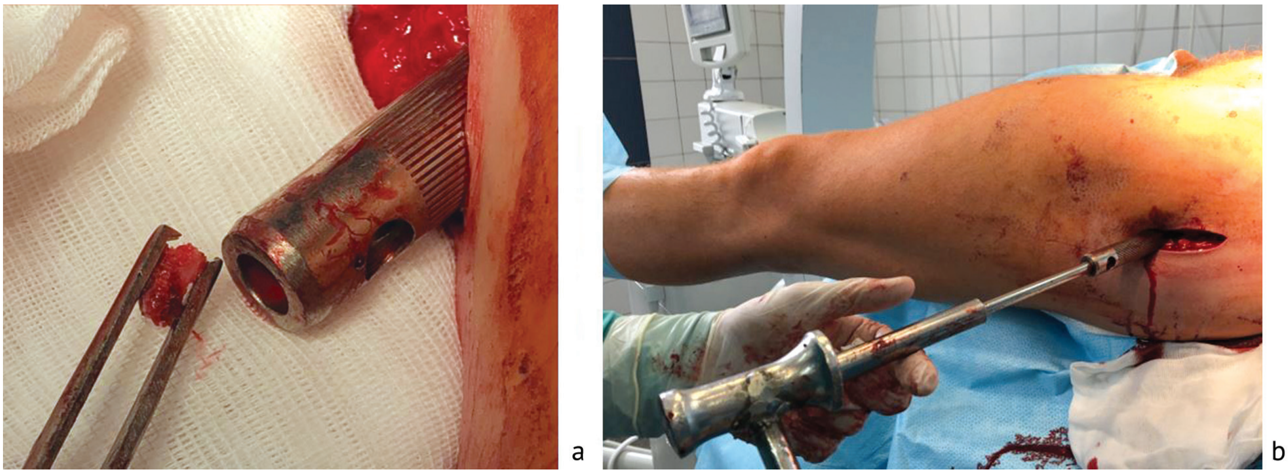

Fig. 6 Introduction of crushed bone autograft with BMAC into the osteonecrosis lesion: a dosed loading through a hollow bone conductor; *b* impaction

Postoperative patient's care On the first day after the operation, all patients underwent radiography of the affected joint (Fig. 7).

Fig. 7 Postoperative radiograph of patient B., 33 years old, which clearly shows the column of bone autograft impacted into the osteonecrosis zone

During the first 4 weeks, axial load on the operated limb was completely excluded. After one month, patients were allowed a dosed load on the leg of 20 % of body weight that gradually increased to full load over 4 weeks. All subjects were prescribed drug therapy in accordance with current recommendations for the treatment of ANFH [1]. The treatment regimen included calcium and vitamin D preparations intake for 3 months, bisphosphonates, anticoagulants for 1 month, and after their cessation antiaggregants for 2 months.

RESULTS

Six months after the surgical treatment, 21 patients (24 %) required joint replacement due to persistent pain and poor clinical and functional state (Fig. 8). According to MRI, the osteonecrotic lesion in this group of subjects occupied more than 30 % of the femoral head in the preoperative period and was accompanied by pronounced trabecular edema, which corresponded to ARCO stage IIC. In the postoperative period, 16 (76.2 %) of those patients had collapse of the articular surface of the femoral head, 5 (23.8 %) continued to complain of pain (more than 6 VAS points) and impaired lower limb function, as a result of which the overall quality of life of the patients significantly decreased. As there was no possibility to objectively assess such patients according to clinical and functional systems, the results of their survey were excluded during statistical data processing.

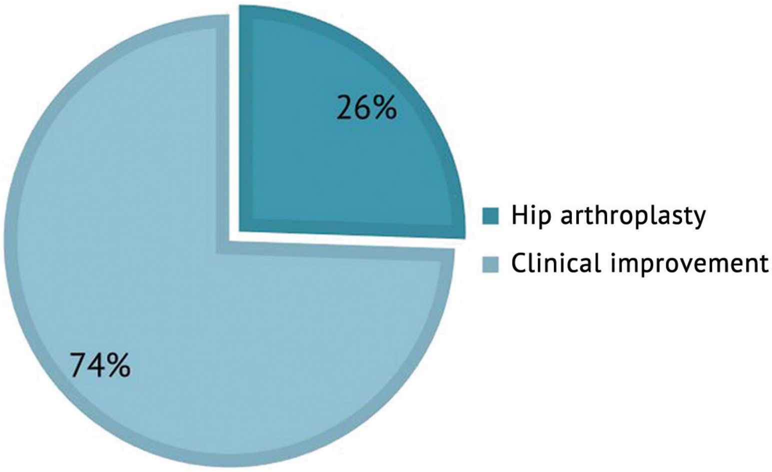

Fig. 8 Proportion of patients who achieved clinical improvement after decompression autoplasty with BMAC and who underwent hip arthroplasty

The obtained average values of the functional state of the hip joint of the remaining 65 patients, assessed with six evaluation systems in the postoperative period, were significantly higher than before the surgical intervention, and the identified differences were not only reliable, but also highly significant ($p < 0.001$).

VAS evaluation of the treatment results in that group of patients who did not require joint arthroplasty showed decrease in the pain level from (6.9 ± 1.4) to (2.4 ± 1.4) points 3 months after surgery. Within 3 to 6 months of follow-up, the pain intensity index remained unchanged and was (2.3 ± 1.3) points, and by 12 months it had smoothly decreased to (1.7 ± 0.5) points.

The modified HHS showed an improvement in the hip joint function in all 65 patients who underwent decompression and bone autografting with BMAC, and whose treatment results were included in the statistical processing of the data. Three months after the operation, the average value reached 76 points, and the result was assessed as fair. After 12 months of follow-up, the indicator increased to 83 points, which corresponded to a good clinical and functional state of the joint.

The assessment of Lequesne life activities restrictions also showed a gradual improvement in such indicators as pain and discomfort, walking distance, and daily activities from “significant” limitation before the operation to “mild” limitation one year after the treatment.

Similar findings were obtained with the UCLA Activity Score. Patients noted a significant increase in motor activity over time. A small increase in indicators at the first time-points was explained by a fairly long rehabilitation period, but by one year from the date of the operation, a significant improvement in functional results was recorded.

Analysis of the patients' quality of life based on a subjective 100-point scale, as well as the Eq-5d questionnaire, showed positive dynamics in mobility, self-care, everyday activity, pain and discomfort, anxiety and depression. According to respondents, their quality of life was estimated at 60 % in the preoperative period, and a year after treatment increased to 85 % (Table 1).

Table 1

Results of the patients' survey at studied observation time-points

Evaluation system	Before intervention	3–6 months after intervention	9–12 months after intervention
VAS	6.9	2.4	1.7
Modified Harris Hip Score	66.6 (poor)	76.6 (fair)	83.6 (good)
Lequesne index (limitation of life activities)	12.8 (marked)	5.5 (moderate)	3.2 (mild)
UCLA Activity Score	2.4	3.6	7.9
Eq-5d (quality of life questionnaire)	10.8	9.1	7.8
Subjective evaluation of quality of life (0–100 %)	60 %	80 %	85 %

In order to assess the morphological changes in the autograft, a histological study of the resected femoral head of one of the patients who underwent joint arthroplasty surgery was performed. The preserved preoperative MRI data allowed us to compare the MRI picture, the visual characteristics of the sawn macropreparation and the results of the histological study.

The comparison of the volume of the femoral head lesion visible on the macropreparation and the volume of the autograft impacted into the osteonecrosis zone revealed that the entire osteonecrotic bone tissue focus was not replaced with the technique applied. The results of the histological study showed that there was no complete restructuring of the autograft. The microscopic picture of the micropreparation corresponded to aseptic bone necrosis with the presence of the fragments of spongy bone tissue, partially lysed bone trabeculae, fibrous foci with inclusions of fatty tissue in the intertrabecular space (Fig. 9).

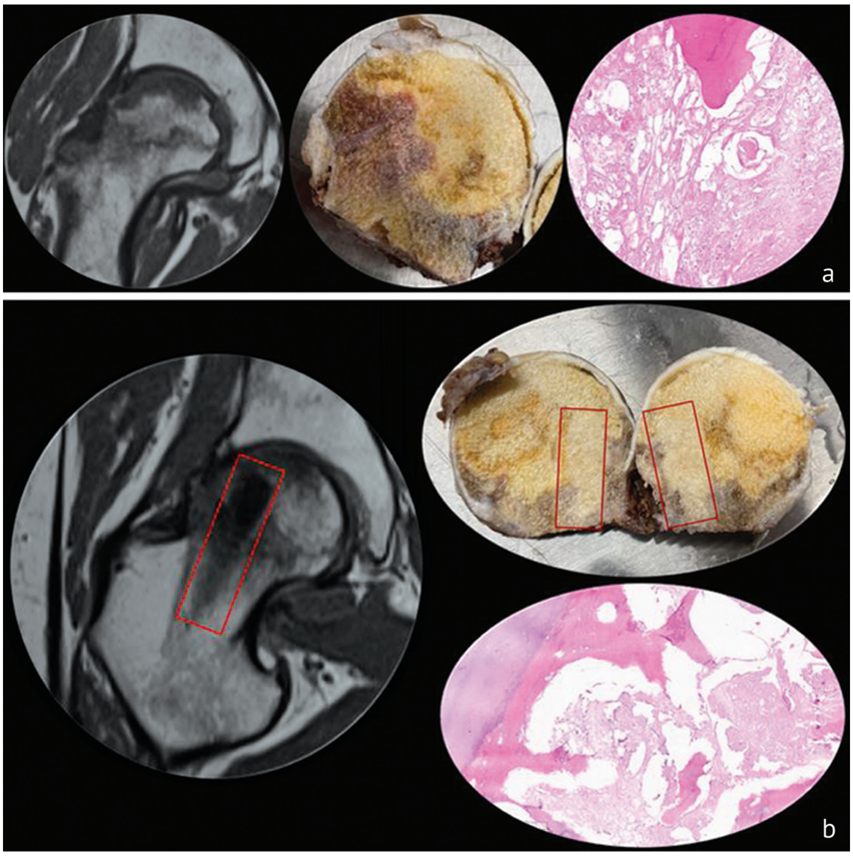

Fig. 9 MRI image, macropreparation and histological image of the femoral head sections in patient K., 43 years old: *a* section without bone grafting areas; *b* section with a column of bone autograft (red rectangle)

One year after the surgical treatment, after comparing the clinical and radiographic findings in the group of 65 patients who did not need joint replacement, 10 cases showed a collapse of the femoral head, 15 cases showed no structural changes in bone tissue, and 40 cases showed regression of trabecular edema of the femoral head and neck despite a good clinical outcome (Fig. 10, 11).

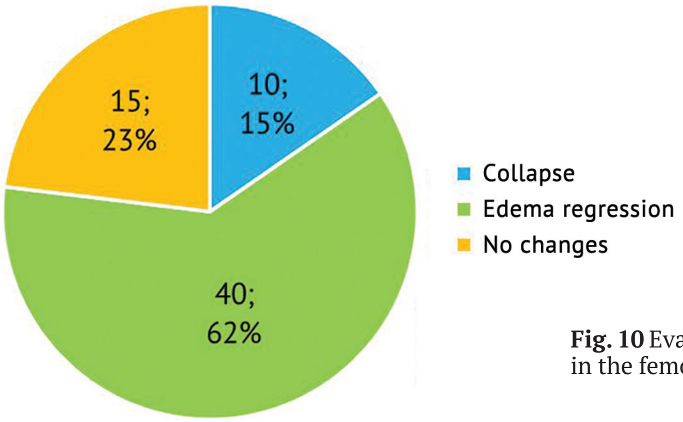

Fig. 10 Evaluation of structural changes in the femoral head based on MRI

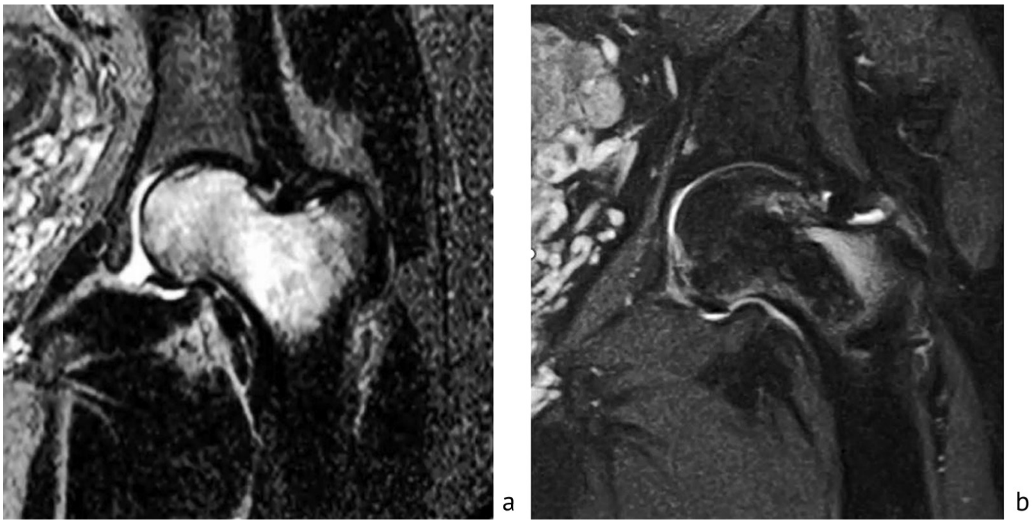

Fig. 11 MRI image of the hip joint of patient T., 45 years old, with ANFH: a before surgery; b 6 months after treatment

During the surgical treatment and subsequent observation, one complication (0.86 %) was detected, neuropathy of the external cutaneous nerve of the thigh, which probably occurred as a result of nerve trauma during the collection of bone autograft from the iliac crest. Paresthesia resolved 6 months after the surgery without drug therapy.

DISCUSSION

Our pilot multicenter prospective non-randomized study demonstrated the effectiveness of minimally invasive decompression and bone autografting combined with BMAC in the treatment of patients with ANFH. Most patients showed a decrease in pain, an improvement in the functional state of the hip joint and overall quality of life at all follow-up time-points.

The surgical treatment tactics used in the study provided arrest of disease progression and prevented the collapse of the femoral head in 55 patients (63.9 %). However, it was not possible to achieve a noticeable regression of pathological structural changes. According to the results obtained, the undertaken minimally invasive surgical intervention allowed 76 % of patients to avoid hip arthroplasty within 12 months of observation.

Decompression of the osteonecrotic lesion proposed by P. Ficat and J. Arlet is a generally accepted technique used over the past decades [31]. It is believed that this surgical intervention may eliminate bone marrow edema and excessive intraosseous pressure, improve local perfusion of bone tissue and create conditions for revascularization of the affected area [26, 30]. Unfortunately, in most cases, the use of core decompression only does not allow for a comprehensive effect on the main links in the ANFH pathogenesis and to obtain the desired treatment result by applying this method. Moreover, according to some researchers, classical core decompression to create a tunnel which is 8–10 mm in diameter without bone grafting, may deprive the subchondral bone of support and provoke its collapse [22, 23, 35]. Due to the high percentage of poor outcomes, independent researchers have attempted to improve organ salvage methods for treating ANFH [32]. The basic concept is to modernize decompression by combining it with various types of vascularized and non-vascularized grafts, as well as applying various synthetic materials [3, 22, 24, 27, 28].

In 1996, Mont et al. reviewed 42 studies to compare the effectiveness of decompression of the osteonecrotic focus and non-operative treatment tactics for patients with ANFH; the treatment results of 2025 people were analyzed. In the group of decompression (n = 1206), the rate of satisfied patients ranged from 53 to 63 %. In the control group (n = 819) of a conservative treatment method, only 22 % of patients achieved positive results [21].

In 2008, Seyler et al. analyzed the treatment results of 33 patients (39 hip joints) with ANFH stages II and III according to the classification of P. Ficat and J. Arlet (1980). All subjects underwent decompression of the osteonecrotic lesion in combination with impaction of a non-vascularized autograft. After 36 months, 26 (67 %) of the 39 hip joints did not require hip arthroplasty; the authors considered the treatment results of their patients successful [33].

In 2023, a group of Indian scientists led by H. Singh performed decompression with autoplasty with a cancellous graft in 20 patients with ANFH stage I and II according to the classification of P. Ficat and J. Arlet (1980). Ninety percent of the subjects were young people aged 20 to 40 years. After 6 months, the authors diagnosed the development of secondary osteoarthritis or signs of osteonecrosis progression to stage III or IV of the disease in 30 % of patients [34].

High rates of poor outcomes of limb preserving surgeries for ANFH were caused mainly by incomplete regeneration of the area of aseptic bone necrosis and directed the search for new approaches to improve treatment results towards regenerative medicine [18, 21, 29, 30].

Autologous bone marrow aspirate and concentrate (ABMC) are among the basic orthobiological products. The mechanism of their action has not been sufficiently studied, but the mesenchymal stromal cells they contain with their paracrine effect and the ability to differentiate along the osteogenic pathway, numerous growth factors, cytokines, and biologically active molecules suggest the potential for using these products to stimulate reparative processes in various types of connective tissue. Experimental studies and the few clinical studies on the use of orthobiological products in the treatment of musculoskeletal diseases and injuries show very encouraging results [22, 26, 27, 28, 36, 37, 40, 41]. As for aseptic necrosis itself, the stimulating effect of ABMC on vascular proliferation has an undoubted pathogenetic significance. Secretion of growth factors in BMAC such as VEGF and PDGF contributes to angiogenesis and reduces ischemia of the affected bone area. Along with this, the anti-apoptotic and immunomodulatory effects of BMAC, achieved by inhibiting TNF-α, as well as IL-1, IL-6, IL-12 and other inflammatory mediators, prevent disease progression and further destruction of the joint [22, 28, 37].

The possibility of core decompression in combination with BMAC introduction was first reported by Hernigou et al. based on the results of a prospective study involving 534 patients with aseptic necrosis of the femoral head stage I and II according to the Steinber classification [38]. The follow-up period ranged from 8 to 18 years (13 years on average). Throughout the study follow-up, 94 patients required joint replacement, which is 17 % of the total number. In patients who did not require joint replacement (*n* = 400), an improvement in the clinical and functional state was found according to the Harris scale (70 points before surgery, 88 points in the postoperative period). The authors noted a direct dependence of the treatment results on the number of progenitor cells administered with the concentrate [26]. The latter was logically consistent with the known fact of a significant decrease in the number of osteoblasts and MSCs in bone tissue during ANFH progression that explains the decrease in the ability of bone tissue to osteogenesis and replacement of the necrotic focus with "living" bone [2, 3, 15, 16].

Some comparative clinical studies showed the advantages of BMAC as an adjunct to conventional surgical treatment. Thus, in a prospective double-blind randomized study by Wang et al., including 45 patients (53 hip joints) diagnosed with ANFH stages I–III, the functional results of decompression of the necrotic lesion combined with bone autografting and BMAC administration after 24 months of observation were significantly better than those in patients who underwent decompression alone. Moreover, in the comparison group, the authors observed MRI signs of disease progression in 33.3 % of cases, and hip arthroplasty was performed in 4 patients. In the main group of patients, negative dynamics were noted in only 8 % of cases, while 2 patients with stage III ANFH required joint arthroplasty [35].

In 2020, Zhang et al. conducted a systematic meta-analysis to evaluate the efficacy of osteonecrotic lesion decompression in combination with BMAC. The work included 16 clinical studies, 7 of which were randomized. The total number of participants was 1051. Patients in the main group (*n* = 583) underwent decompression in combination with cell therapy, and in the comparison group (*n* = 468) only femoral head decompression was used. The results were assessed over 24 months based on the VAS and Harris scales, as well as the patients' need for total joint arthroplasty. According to the final results, the evaluation scores were higher in the group where osteonecrotic lesion decompression was combined with the use of an autologous bone marrow aspirate product. After the treatment, hip replacement was required in 22.5 % and 43.3 % of patients in groups 1 and 2, respectively [36]. In general, according to the systematic review by Zhang et al. and a number of other case studies in recent years, positive outcomes of surgical treatment using decompression in combination with BMAC at precollapse stages of the disease can be achieved in 70–90 % of cases, which is 20 % higher compared to using decompression alone, without bone marrow concentrate [21, 33, 34, 35, 36].

The aim of our study was to evaluate the impact of minimally invasive decompression, bone autografting combined with BMAC on hip function and quality of life in patients with ANFH, as well as on pathological structural changes occurring in the femoral head.

According to the data obtained, we achieved successful treatment outcomes in 76 % of cases. Due to the fact that the presented study mainly included patients with post-COVID and steroid-induced osteonecrosis, and there were no subjects with the first stage of the disease, the rate of positive treatment results was slightly lower compared to other similar studies. It also cannot be ruled out that the stage of the disease might have been determined incorrectly in some patients. The reason for this was the high intensity of bone marrow edema on MR images, as a result of which the symptoms of subchondral bone tissue lysis might have remained undetected. Meanwhile, it is these changes that are identified as the "crescent symptom" and are considered a pathognomonic sign of stage IIIA according to the ARCO classification, in which organ salvage treatment methods are recognized as ineffective in most cases [25, 26, 28, 30, 35].

Along with the uncontroversial need to consider the staging of ANFH for choosing treatment tactics, our work also confirmed the no lesser importance of assessing the extent of the femoral head lesion. In patients with stage II and a lesion volume of up to 30 %, the need for hip replacement after minimally invasive decompression in combination with bone autografting combined with BMAC was relatively low. For patients with stages IIIB and IV, hip arthroplasty remains the optimal solution, since in their cases the likelihood of secondary osteoarthritis remains extremely high [18, 21, 29, 30, 35, 38].

The limitations of our study were a relatively small sample size, the absence of a control group and patients with the first stage of the disease. Moreover, the follow-up was short, and the clinical and functional systems of evaluation were mainly based on the subjective opinion of the respondents.

CONCLUSION

The study showed the effectiveness of minimally invasive decompression and bone autografting combined with BMAC in the treatment of patients with ANFH. In most cases, a decrease in the level of pain, improvement in the functional state of the hip joint and quality of life of patients at all follow-up points of the study were observed. However, no noticeable regression of pathological structural changes in the bone tissue was revealed. To obtain more objective data on the effectiveness of BMAC in the surgical treatment of ANFH, it is necessary to conduct a study with a larger sample of patients and a control group, as well as an analysis of long-term treatment results.

Conflict of interests *The authors declare no obvious or potential conflicts of interest related to the publication of this article.*

Funding source *State funding.*

Ethical statement *The study was approved by institutional ethics committee (registration number: IRB 00005839 IORG 0004900 (OHRP)).*

Informed consent *Patients gave voluntary written informed consent to participate in the study and publish its results.*

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The article was submitted 29.07.2024; approved after reviewing 27.09.2024; accepted for publication 21.10.2024.

Information about the authors:

Daria A. Naida — Candidate of Medical Sciences, Head of the Department, Darianayda@gmail.com, https://orcid.org/0000-0003-4567-2612;

Boris V. Tyulkevich — orthopedic surgeon, Head of theDepartment, 1983loki@mail.ru, https://orcid.org/0009-0004-2123-2182;

Dmitry A. Malanin — Doctor of Medical Sciences, Professor, Head of the Department, malanin67@mail.ru, https://orcid.org/0000-0001-7507-0570;

Vladimir V. Kondrashenko — orthopedic surgeon, graduate student vovamail2009@yandex.ru, https://orcid.org/0000-0001-7512-492X;

Maxim V. Demeshchenko — Candidate of Medical Sciences, Associate Professor, maximus275@yandex.ru, https://orcid.org/0000-0003-1797-2431;

Nikolay N. Chirkov — Doctor of Medical Sciences, orthopedic, Head of the Department, surgenik@gmail.com, https://orcid.org/0000-0001-7099-2672.