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Revision and Complex Primary Total Hip Arthroplasty with Impaction Bone Grafting for Acetabular Defects: Medium-Term Results

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Abstract

Background. Impaction bone grafting remains an alternative method for managing bone deficiency. Cyclic loads on the allograft may cause its further compaction and deformation, leading to migration of the acetabular component.

The aim of this study — to evaluate the effectiveness and refine the indications for the use of impaction bone grafting for acetabular defects in revision and complex primary total hip arthroplasty by assessing the mid-term survival of implanted cemented acetabular components.

Methods. We performed a retrospective analysis of the results of impaction bone grafting in 48 patients whose data were available for the assessment of acetabular component survival. Radiographic data were analyzed in 42 cases, clinical outcomes were assessed in 44 cases. Structure of operations was represented by 37 revisions and 5 cases of complex primary hip arthroplasty. The average follow-up period was 60 months. We assessed radiographic signs of cup migration, loosening and bone allograft remodeling. Kaplan-Meier survival analysis with 95% confidence intervals was performed.

Results. The general survival of acetabular components was 97.9% (95% CI: 97.86-97.94) for 60 months and 84.3% (95% CI: 84.15-84.43) for 90 months. In 4 (7.4%) cases, we recorded an unsatisfactory result. In 7 cases, radiolucent lines without clinical signs of loosening were detected. In 22 (52.3%) cases a simultaneous change in inclination and cranial displacement of the rotation center were noted. In isolated assessment of inclination, changes were noted in 24 (57.1%) cases. We found a direct correlation between the acetabular component migration, defect severity and the use of a containment device ($p = 0.006$), as well as between the displacement of the rotation center by more than 5 mm and the inclination by more than 10° in 91.7% of cases ($p < 0.0001$). The median functional assessment according to the Hip Harris Score showed 85.50 [70.5; 95.0] points and 6.5 [2.0; 21.0] points according to the WOMAC questionnaire.

Conclusions. Impaction bone grafting is a method of choice for limited bone defects replacement. Migration of the cup, displacement of the rotation center by more than 5 mm and an increase in its inclination by more than 10° can be regarded as a conditional norm due to natural biomechanical processes, which is confirmed by high medium-term survival rates of the implant according to clinical data.

Keywords: impaction bone grafting; bone defect; revision arthroplasty; acetabular component migration; Kaplan-Meier survival analysis.

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Среднесрочные результаты ревизионного и первичного сложного эндопротезирования тазобедренного сустава с применением импакционной костной пластики дефектов вертлужной впадины

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Реферат
Актуальность. Импакционная костная пластика остается альтернативным способом возмещения костного дефицита. Циклические нагрузки на аллотрансплантат могут вызывать его дальнейшее уплотнение и деформацию, приводя к миграции вертлужного компонента.
Цель исследования — оценить эффективность и уточнить показания для применения импакционной костной пластики дефектов вертлужной впадины при ревизионном и первичном сложном эндопротезировании тазобедренного сустава путем определения среднесрочных результатов выживаемости имплантированных вертлужных компонентов цементной фиксации.
Материал и методы. Проведен ретроспективный анализ результатов применения импакционной костной пластики у 48 пациентов, данные которых были доступны для оценки выживаемости вертлужного компонента. Рентгенологические данные проанализированы в 42 случаях, оценка клинических результатов проведена в 44 случаях. Структура операций представлена 37 ревизионными вмешательствами и 5 операциями первичного сложного эндопротезирования. Средний срок наблюдения составил 60 мес. Оценены рентгенологические признаки миграции, расшатывания вертлужного компонента, перестройки костного аллотрансплантата. Проведен анализ выживаемости по Каплану – Майеру с 95% доверительными интервалами.
Результаты. Общая выживаемость эндопротезов, в частности вертлужных компонентов, составила 97,9% 95% ДИ: 97,86–97,94) за 60 мес.; 84,3% (95% ДИ: 84,15–84,43) за 90 мес. В 4 (7,4%) случаях зафиксирован неудовлетворительный результат. В 7 случаях выявлены рентгенопрозрачные линии без клинических признаков расшатывания. В 22 (52,3%) случаях отмечено одновременное изменение инклинации и краниальное смещение центра ротации. При изолированной оценке инклинации изменения отмечены в 24 (57,1%) случаях. Выявлена прямая корреляция миграции вертлужного компонента, тяжести дефекта и использования ограничивающей конструкции ($p = 0,006$), а также между смещением центра ротации более 5 мм в любом направлении и увеличением инклинации более чем на 10° в 91,7% случаев ($p < 0,0001$). Медиана функциональной оценки по шкале Харриса показала 85,50 [70,5; 95,0] балла и 6,5 [2,0; 21,0] балла согласно опроснику WOMAC.
Заключение. Импакционная костная пластика является методом выбора для замещения ограниченных костных дефектов при ревизионном эндопротезировании тазобедренного сустава. Миграцию вертлужного компонента, смещение центра ротации более 5 мм и увеличение его инклинации более 10° можно расценивать как условную норму, обусловленную естественными биомеханическими процессами, что подтверждается высокой среднесрочной выживаемостью эндопротеза.
Ключевые слова: импакционная костная пластика; костный дефект; ревизионное эндопротезирование; миграция вертлужного компонента; анализ выживаемости по Каплану – Майеру.

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INTRODUCTION

Bone defect restoration remains a key prerequisite for successful hip joint reconstruction during revision arthroplasty, along with restoration of the center of rotation and achievement of stable component fixation [1, 2]. In recent decades, there has been a growing trend in hip reconstructive surgery toward the use of modular revision systems made from various porous materials with pronounced osteoconductive properties [3, 4].

Nevertheless, interest in the use of various bone grafting materials (BGM) remains high. The use of massive structural allografts is limited due to the risk of resorption and reduced long-term stability, as bone remodeling occurs only partially in the revascularized peripheral zone [5]. An alternative method of managing bone defects currently involves impaction bone grafting (IBG) using morselized allograft bone. Numerous studies have demonstrated satisfactory outcomes with IBG in combination with cementless highly porous acetabular components [6, 7], modular revision systems [8, 9, 10], cages [11], reconstruction rings, and custom implants [12], where the mechanical support is provided by the native bone while the allograft fills the defect cavity. Most of the clinical experience with IBG in hip arthroplasty has been associated with cemented fixation of the acetabular component [13, 14, 15, 16, 17].

A distinctive feature of this approach is the potential for changes over time in the spatial position of the acetabular component, which rests on a bed of impacted morselized allograft bone. This characteristic is an inherent aspect of the technique and is likely related to the fact that the bone graft material undergoes additional compaction and deformation under cyclic loading [18]. This fundamentally differs from the implantation of the acetabular component into native acetabular bone, which does not undergo significant structural changes under cyclic loads. Despite the known limitations of IBG, such as the risk of resorption of the impacted bone graft [19], lower initial stability of cemented acetabular component, and potential for migration [20, 21], the biological potential for restoring acetabular bone defects remains an attractive advantage of this technique.

The aim of this study – to evaluate the effectiveness and refine the indications for the use of impaction bone grafting for acetabular defects in revision and complex primary total hip arthroplasty by assessing the mid-term survival of implanted cemented acetabular components.

METHODS

Study design

A single-center retrospective observational study was conducted to evaluate the outcomes of impaction bone grafting using the X-Change system with specialized instrumentation (Stryker Howmedica, Newbury, UK) in revision and complex primary total hip arthroplasty (THA) in patients operated on between September 2015 and February 2022 at the Federal Center of Traumatology, Orthopedics, and Arthroplasty (Barnaul, Russia).

Inclusion criteria were as follows:

1) revision or complex primary THA;

2) contained or combined (with segmental deficiency) acetabular bone defects requiring reconstruction;

3) use of IBG in combination with a cemented acetabular component.

The exclusion criterion was the use of alternative techniques for acetabular defect reconstruction, including cementless acetabular components with augments, reconstruction cages, or structural allografts.

Initially, 54 patients meeting the inclusion criteria were selected. By the time of mid-term follow-up assessment, 6 patients were lost to follow-up and could not be contacted or examined. Three patients had died from causes unrelated to the surgical procedure; however, available clinical data and X-rays obtained during their follow-up period were included in the study. As a result, data from 48 patients were included in the final survival analysis of cemented acetabular components. Radiographic data were analyzed in 42 cases (37 patients who underwent revision procedures and 5 patients who underwent complex primary THA), and clinical outcome questionnaires were completed by 44 patients.

Baseline patients' characteristics

The study included 23 (47.9%) women and 25 (52.1%) men. The mean age at the time of surgery was 59.8 years (range, 35-78 years); 21 patients were under 60 years of age, and 27 patients were aged 60 years or older. The mean body mass index (BMI) was 28.55±4.9 kg/m^2 (range, 18.2-39.0). Twelve patients (25.0%) had normal weight, 17 (35.4%) were overweight, 14 (29.2%) had class I obesity, and 5 (10.4%) patients had class II obesity. The mean follow-up period was 60 months (range, 12-111 months).

The indications for the use of IBG were determined based on preoperative evaluation in cases of contained acetabular bone defects or combined defects with a segmental component, provided that the defect could be augmented with various metal constructs and converted into a fully contained defect capable of retaining the BGM.

Initially, revision arthroplasty accounted for 47 of the performed procedures. Of these, 30 cases were due to aseptic loosening, 2 cases due to osteolysis, and 1 case due to a massive post-explant acetabular defect following a failed reconstruction attempt using alternative methods. In 13 cases, IBG was performed during the second stage of treatment for periprosthetic joint infection (PJI), and in 1 case during single-stage treatment for PJI. In 7 cases, acetabular bone grafting was performed during primary THA: in 1 case for a massive osteolytic cyst, in 1 case for femoral head avascular necrosis with a secondary acetabular defect, in 1 case during two-stage treatment of arthritis following femoral head osteomyelitis, and in 4 cases for *protrusio acetabuli*. In 26 cases, revision of the acetabular component was combined with the exchange of the femoral component, and in 11 cases IBG was performed on both the pelvis and femur simultaneously.

Surgical technique

All procedures were performed via an anterolateral approach by three experienced surgeons, each with over 10 years of surgical practice. Intraoperatively, the condition of the acetabulum and the extent of any segmental bone defects were assessed. In areas of the acetabulum where bone loss resulted in uncontained defects, a metallic reconstruction mesh (X-Change, Stryker Howmedica, Newbury, UK), a custom-made 3D-printed titanium mesh (Logeeks MS, Novosibirsk, Russia) manufactured via selective laser melting, or a porous tantalum augment (Zimmer, Warsaw, Indiana, USA) was used. The distribution of constructs used for acetabular defect augmentation is presented in Table 1. The bone graft material (chips approximately 10 mm^3 in size) was manually prepared from thermally disinfected allograft bone obtained from the institutional bone bank using Luer rongeurs. Cemented acetabular components from various manufacturers, ranging in size from 40 to 58 mm, were implanted. Patients were mobilized on the first postoperative day, followed by partial weight-bearing on the operated limb for 6 weeks.

Outcome assessment methods

At the time of the study, patients were invited for a follow-up visit, during which X-rays of the hip joint were obtained in anteroposterior and axial views. A clinical examination was performed, including assessment of functional outcomes using the modified Harris Hip Score (HHS) [22]

Table 1

Methods of bone defect augmentation in acetabular reconstruction

Augmentation method	Number of cases
Without a construct	19
Reconstruction of a peripheral defect using the Stryker mesh	20
Reconstruction of a medial wall defect using the Stryker mesh	2
Reconstruction of peripheral and medial defects using the Stryker mesh	6
Reconstruction using a custom-made 3D-printed mesh	3
Porous tantalum augment	4

and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [23]. Patients who were unable to attend an in-person visit were interviewed by phone, and their X-rays were requested by mail and subsequently analyzed.

Based on preoperative X-rays, computed tomography data, and intraoperative findings, acetabular defects were classified according to their containment and severity using the American Academy of Orthopaedic Surgeons (AAOS) classification [24] and the W. Paprosky classification [25], respectively. In revision arthroplasty cases, the distribution of defects according to the Paprosky classification was as follows: type 3B in 27 (57.4%) cases, type 2A in 18 (38.3%) cases, and types 2B and 2C in one case (2.1%) each. Uncontained defects (Type I) were observed in 2 (4.3%) cases, while the remaining cases included contained defects (Type II) in 11 (23.4%) patients and combined defects (Type III) amenable to reconstruction and conversion into fully contained defects in 34 (72.3%) cases. Among complex primary arthroplasty cases, contained defects (Type II) were identified in 5 cases and combined defects (Type III) in 2 cases (Table 2).

In evaluating implant survival – specifically, that of the acetabular component – radiographic signs of loosening at the study endpoint or removal of the acetabular component during the follow-up period after revision surgery were considered as failure outcomes.

To assess changes in the position of the center of rotation of the acetabular component over time, a horizontal reference line (X-axis) was drawn through the inferior margin of the "teardrop" figure on both hips. A perpendicular line (Y-axis) was then drawn from the lateral edge of the "teardrop" on the operated side. Horizontal and vertical distances from the center of the prosthetic femoral head were measured by projecting perpendiculars from the head center to the X and Y axes [26]. Additionally, we measured the inclination angle of the acetabular component relative to the X-axis and its anteversion (Figure 1).

The magnitude of acetabular component displacement was determined by calculating the difference between the initial and final positions of the center of rotation along the X and Y axes. Similarly, changes in inclination and anteversion angles were assessed. Calibration of radiographic images was performed using DICOM files, and all measurements were conducted with the BonaPlanner 2D software, utilizing the "postoperative control" function.

Table 2

Distribution of bone defects according to the W. Paprosky and AAOS classifications

W. Paprosky		AAOS	
Type	Number	Type	Number
Revision arthroplasty (n = 47)			
Type 2C	1	Type I	1
Type 2B	1	Type III	1
Type 2A	18	Type II	7
		Type III	11
Type 3B	27	Type I	1
		Type II	4
		Type III	22
Complex primary total hip arthroplasty (n = 7)			
No		Type II Type III	5 2

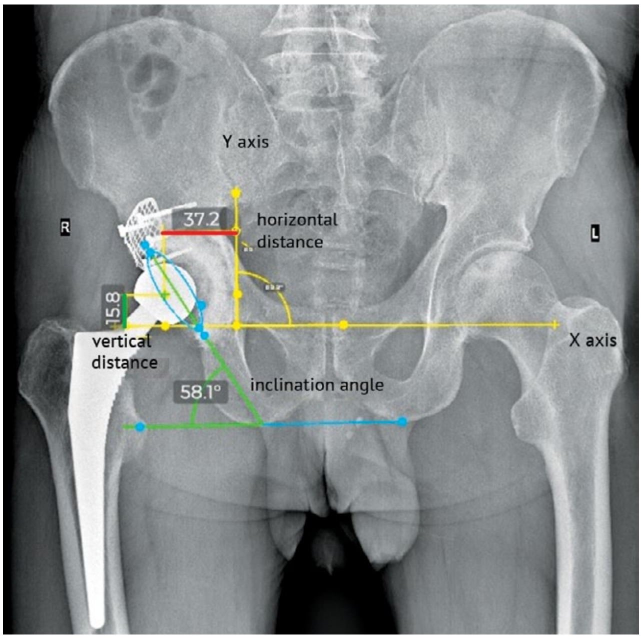

Figure 1. Scheme of acetabular component displacement measurements

Radiographic assessment of the bone allograft was performed using the criteria described by T.J. Slooff et al. [27]. Complete graft incorporation was defined as radiographic density of the graft identical to that of the host bone, with continuous trabecular patterns throughout the interface. Radiolucent lines at the bone-cement interface were evaluated according to the three-zone system described by J.G. DeLee and J. Charnley [28]. The outcome was considered unsatisfactory in the presence of radiolucent lines in all three zones, mesh breakage or screw migration, or dislocation of the acetabular component.

Statistical analysis

The study data were analyzed using both parametric and non-parametric statistical methods. Data collection, correction, organization, and visualization were performed using Microsoft Office Excel 2016. Statistical analysis was conducted with MedCalc software. Continuous variables were described using the median (Me) and interquartile range [Q_1; Q_3]. Categorical variables were presented as absolute values and percentages.

For comparisons of means in normally distributed continuous variables, the Student's t-test was applied; the difference considered statistically significant at $p < 0.05$. In cases of non-normally distributed data, the Mann-Whitney U test was used for comparisons between independent groups. For normally distributed data across multiple groups, one-way analysis of variance (ANOVA) was performed using the F-test. Associations between categorical variables were assessed using contingency tables and Pearson's chi-squared (χ^2) test. Kaplan-Meier survival analysis was performed with 95% confidence intervals (CI). Endpoints included aseptic loosening, radiographic signs of aseptic loosening, and revision for any reason (aseptic loosening or infection) in the analysis of overall implant survival.

RESULTS

During the follow-up period, no revision procedures were performed in 44 (91.7%) cases. Complications occurred in 4 (4.2%) cases, of which 2 (4.2%) cases required surgical intervention due to recurrence of the infectious process. In another 2 (4.2%) cases, radiographic signs of aseptic loosening were identified, for which revision surgeries have been scheduled. Thus, the overall prosthesis survival rate, specifically of the femoral component, with aseptic loosening or re-operation as the endpoint, was 97.9% (95% CI: 97.86-97.94) at 60 months and 84.3% (95% CI: 84.15-84.43) at 90 months (Figure 2). The survival rate with aseptic loosening as the endpoint was 100% at 60 months and 90.9% (95% CI: 90.78-91.02) at 90 months (Figure 3).

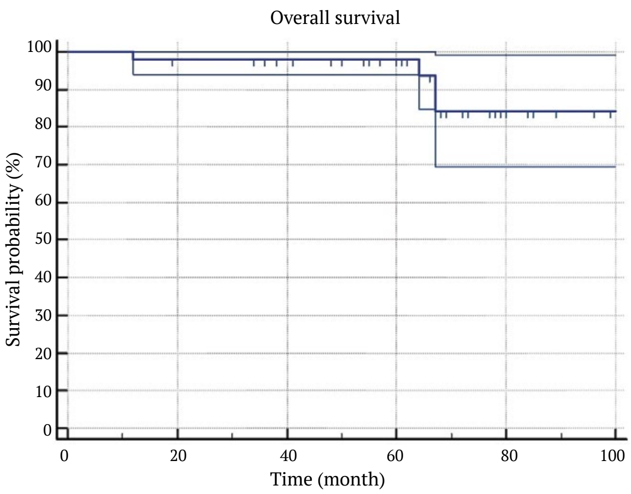

Figure 2. Kaplan-Meier curve for overall cup survival

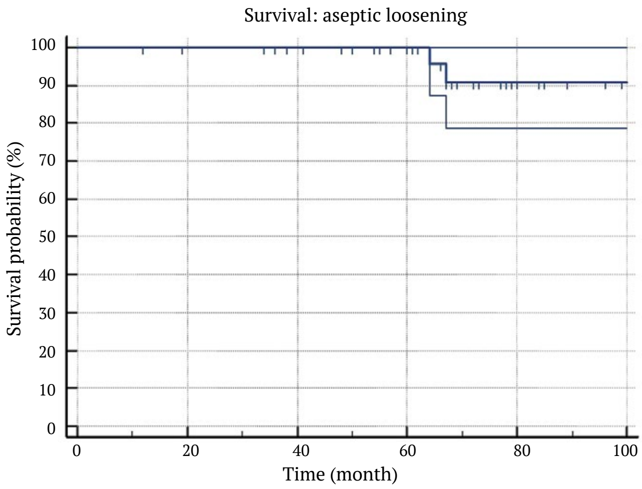

Figure 3. Kaplan-Meier curve for cup survival with revision aseptic loosening as the endpoint

Complications were observed in 6 (11.11%) patients: in two cases, intraoperative perforation of the femoral canal wall occurred during the removal of the femoral component of the prosthesis. In one case, sciatic nerve neuropathy developed, which regressed within 6 months with conservative treatment. In 3 cases, dislocation of the femoral component occurred. In one of these cases, due to recurrent dislocations, a re-operation was required, involving implantation of a dual mobility system into an impacted bone graft bed following the removal of the acetabular component using the "cement-in-cement" technique prior to the patient's discharge. This case was not classified as an unsatisfactory outcome. No mortality was recorded in the study group.

Control X-rays were analyzed in 42 patients. Reliable signs of the acetabular component loosening were identified in only 4 (9.5%) patients. In two (4.8%) cases the dislocation of the cup beyond the boundaries of the acetabulum was observed. In one (2.4%) case there was noticed the presence of a radiolucent line at the graft-cement interface in all three zones. In one (2.4%) case a radiolucent line in zone III was associated with a high degree of migration (> 5 mm along one of the axes), a change in anteversion within 10°, and a low HHS value of 37 points. Radiolucent lines were detected in 7 (16.7%) cases: in 6 patients, they were observed in only one zone, most frequently in zone III, and in one case, a radiolucent line was found in two zones (zones II and III).

Midterm radiographic assessment of the position of the center of rotation, inclination, and anteversion of the acetabular component revealed simultaneous changes in inclination and cranial displacement of the center of rotation in 22 (52.4%) cases. An increase in acetabular component inclination was observed in 24 (57.1%) cases, indicating that changes in inclination occurred in nearly all cases with cranial displacement of the center of rotation. A direct correlation was identified between the displacement of the center of rotation by more than 5 mm in any direction and an increase in inclination by more than 10°, occurring in 91.7% of cases ($p < 0.0001$). The analysis showed that significant displacement of the center of rotation (> 5 mm) most commonly occurred in the cranial direction: 8 (19.0%) cases along the Y-axis and 3 (7.1%) cases along the X-axis. Types of acetabular component migration in relation to bone defect classification and reconstruction method are presented in Table 3.

Table 3

Major indicators for acetabular component migration

Patient's number	Δ of inclination, deg.			Displacement of the center of rotation, mm: Along the X-axis			Displacement of the center of rotation, mm: Along the Y-axis			Paprosky	AOOS	Reconstruction method
	0	<10	>10	0	<5	>5	0	<5	>5			
1*			•			•			•	2A	III	C
2		•			•				•	3B	III	C2
3	•			•			•			3B	II	0
4			•		•			•		2A	III	C2
5	•			•			•			3B	III	C
6			•			•			•	3B	III	C2
7	•			•			•			–	III	A

End of Table 3

Patient´s number	Δ of inclination, deg.			Displacement of the center of rotation, mm						Paprosky	AOOS	Reconstruction method
				Along the X-axis			Along the Y-axis					
	0	<10	>10	0	<5	>5	0	<5	>5			
8	•				•				•	2A	III	C2
9	•			•			•			2B	I	C
11		•			•			•		2A	III	C
12	•			•			•			3B	III	C2
13		•			•			•		3B	III	C
14	•			•			•			3B	III	CM
15	•			•			•			2A	III	C
16	•				•			•		3B	III	A
17	•			•			•			2A	II	0
18		•			•				•	3B	III	C2
19*			•			•			•	3B	III	C
20*			•			•			•	–	III	3D
21		•		•			•			2A	II	0
22			•		•				•	3B	III	3D
24		•		•			•			3B	II	0
24*			•			•			•	2A	III	C
25	•				•			•		2A	III	C
26	•				•			•		2A	II	0
27		•				•			•	3B	III	C
28	•			•			•			3B	III	A
29		•			•				•	3B	III	C
30	•			•			•			3B	III	CM
31		•		•			•			3B	III	3D
32			•		•				•	3B	III	C
33		•		•			•			–	II	0
34		•		•			•			2A	II	0
35		•		•			•			–	II	0
36		•		•			•			2C	III	A
37	•			•			•			2A	II	0
38		•			•			•		2A	II	0
39		•			•			•		2A	III	C
40	•				•			•		3B	II	0
41	•				•			•		3B	II	0
42		•		•			•			–	II	0
Total	18	16	8	20	16	6	20	10	12			

* — patients with unsatisfactory outcomes, C — a mesh along the acetabular rim, C2 — a mesh along the acetabular rim and medial acetabular wall, CM — a mesh along the medial acetabular wall, 3D — a custom-made 3D-printed mesh along the acetabular rim, A — an augment, 0 — no constructs used.

In the group of patients without the use of any constraining implants (13 cases), the displacement of the center of rotation was observed in 30.8% of cases, with migration occurring within 5 mm (Figure 4).

The use of any type of mesh to contain acetabular bone defects was associated with a change in the position of the acetabular component in 68.0% of cases, i.e., with the displacement of the center of rotation, an increase in inclination, or both. In 44.0% of these cases, the displacement of the center of rotation was significant, being greater than 5 mm along any axis. At the same time, when augments were used, only two out of four cases demonstrated minor changes in acetabular component position (displacement within 5 mm and inclination change less than 10°).

A direct correlation was found between the occurrence of acetabular component migration and the type and severity of bone defect, as well as the use of a containment device. An increased frequency of any degree of migration was observed in the presence of AAOS type III and Paprosky type 3B defects when any type of mesh was used along the acetabular rim ($p = 0.006$).

The mean change in anteversion in the midterm follow-up compared to the immediate postoperative value was 2.8° (range: 0.5-4.5). However, this parameter was not analyzed in detail due to its projection variability depending on pelvic positioning during radiographic examination.

No correlation was found between the displacement of the acetabular component's center of rotation and the diameter of the cup used ($p = 0.3457$), BMI ($p = 0.5726$), or patient age ($p = 0.3457$). No statistically significant associations between these parameters were identified.

In our cohort, functional outcomes assessed using the HHS questionnaire showed a baseline median value of 44.0 points (range: 37.0-55.0), which improved to 85.5 points (range: 70.5-95.0) at the final follow-up. According to the WOMAC questionnaire, baseline scores averaged 47.0 points (range: 45.0-52.0), improving to 6.5 points (range: 2.0-21.0) by the end of the study, indicating good to excellent outcomes.

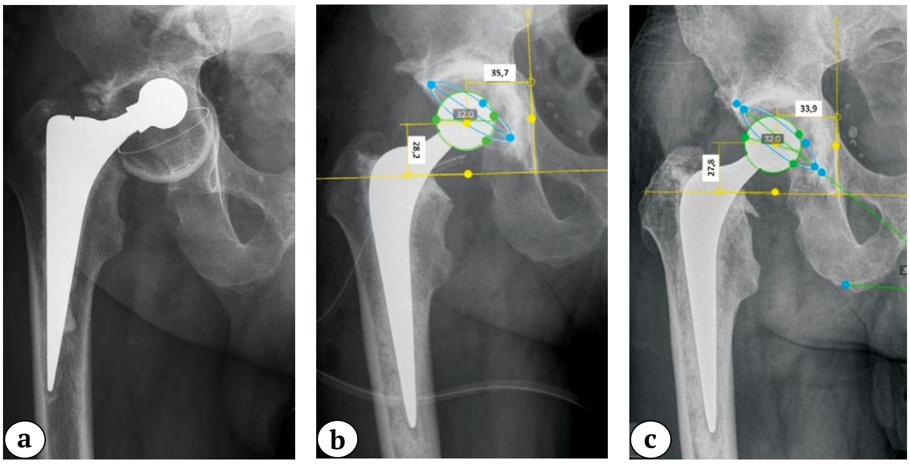

Figure 4. Clinical example of IBG without augmentation:
a — aseptic loosening of the acetabular component with contained acetabular bone defect AAOS type II, Paprosky type 2A, femoral component malposition; b — right hip X-ray after acetabular and femoral IBG with Stryker Exeter/Contemporary cemented fixation; c — control X-ray after 68 months with clear signs of allograft remodeling without component migration

DISCUSSION

The choice of surgical technique depending on the size and shape of bone defects in revision arthroplasty remains a relevant issue [1]. Modern modular revision systems and additive technologies address most problems related to acetabular reconstruction. Nevertheless, in certain cases, impaction bone grafting (IBG) remains the method of choice [29]. As with all techniques used to manage massive bone defects in revision arthroplasty, IBG is associated with less favorable long-term outcomes compared to primary arthroplasty. However, subsequent revisions following IBG may prove more successful, as a greater amount of bone stock is often preserved compared to the pre-revision state. This is particularly important for patients who have undergone multiple revisions or for younger individuals likely to require additional surgeries later in life [30, 31, 32].

In our study, midterm outcomes demonstrated a relatively high reliability of impaction bone grafting in the reconstruction of large bone defects. The overall implant survival rate was 97.9% at 60 months and 84.3% at 90 months. The results obtained in our study are comparable to those reported by other authors who have used similar approaches. M.A. Buttaro et al. reported a 90.8% survival rate in their study involving IBG, metallic mesh, and cemented cup fixation in patients with uncontained acetabular defects undergoing revision total hip arthroplasty, with a mean follow-up of 36 months [33]. B.W. Schreurs et al. reported 96% and 84% cup survival rates at 10 and 15 years, respectively, in patients who underwent acetabular revision using IBG and cemented components [34]. S. Rohe et al., in a midterm study involving 56 patients treated with IBG, also demonstrated a high survival rate of 88% at 7.8 years [12]. However, in the latter study, the authors used IBG in combination with various uncemented fixation constructs.

The term "impaction bone grafting" is broad in orthopedic and trauma surgery and generally refers to the compaction of morselized allograft, with or without the use of additional implants [35]. It is important to emphasize that the present study focuses exclusively on cases involving the X-Change technique, in which the cemented fixation of the acetabular component is performed directly onto the impacted allograft. From a biomechanical perspective, the graft behaves like soil, exhibiting typical changes in its properties under cyclic loading [18]. A key feature of IBG is that load transfer occurs through the cement mantle into the graft, with the bone cement playing an additional stabilizing role for the graft material [36]. The success of IBG using the X-Change technique typically depends on the balance of numerous factors, including the quality of the allograft, the size of the bone chips, and the surgical technique employed to achieve proper impaction [37].

The analysis of midterm outcomes in our study is largely based on previously described biomechanical aspects of the IBG technique, which suggest that spatial changes in the position of the cemented acetabular component along with the cement mantle are virtually inevitable. These changes are attributed to the compaction processes of the graft material during the postoperative period under the influence of cyclic loading resulting from the patient's daily physiological activity [18, 38].

During the measurement and interpretation of the obtained data, we encountered certain methodological limitations. The described method for measuring the displacement of the center of rotation has a margin of error of 3 mm [26]. According to C. Yang et al., even migration of up to 2 mm may be classified as early loosening [39]. Based on these considerations, the measurements of center of rotation displacement in our study were grouped using 5 mm intervals.

The evaluation of the center of rotation and inclination changes showed that acetabular component migration occurred in 24 cases (57.1%). We found no statistically significant correlation between defect size and the degree of component migration. However, we observed a clear pattern: in 68% of cases, migration occurred in patients in whom various types of meshes were used to contain segmental defects along the acetabular rim. In half of these cases, the displacement exceeded 5 mm. This group included patients undergoing revision arthroplasty for AAOS type III defects with Paprosky type 3B severity. Notably, all four patients with unfavorable outcomes also belonged to this group. In contrast, in cases where no additional reconstruction of the acetabular rim was performed, the migration rate was under one-third and the displacement did not exceed 5 mm. Acetabular component migration following IBG has been described by many authors in both earlier [40, 41] and more recent studies [18, 21, 39]. It is evident that in cases with minor defects, where partial load on native bone is achievable, the biomechanical conditions are more favorable than in defects where the load is borne entirely by the impacted allograft, as seen in Paprosky type 3B defects with segmental loss.

E. García-Rey et al. demonstrated differences in long-term outcomes depending on defect type and the use of mesh along the acetabular rim [19]. The 15-year survival rate was 89.1±14.0% when no mesh was required, 84.9±12.0% when mesh was used for medial defects only, 79.6±12.0% when mesh was placed along the rim, and just 53.9±22.0% when both medial and rim meshes were needed (log-rank test, $p = 0.008$).

Migration likely depends to a great extent on the balance between the biological remodeling processes of the graft, its plastic deformation, and the compaction caused by interfragmentary motion of the morselized allograft under cyclic loading, in other words, on which process predominates first. M.Y. Abu-Zeid et al. demonstrated that, according to the Paprosky and AAOS classifications, the smaller the acetabular defect, the greater the likelihood of complete graft incorporation ($p < 0.001$). The average graft layer thickness was significantly higher in patients with partial incorporation compared to those with complete incorporation: 15.5 ± 3.8 mm vs. 10.0 ± 2.2 mm, respectively ($p < 0.001$) [35].

When evaluating acetabular component migration, most authors focus on the displacement of the center of rotation. In our study, we also observed a consistent increase in inclination in nearly all cases where a reconstruction mesh was used ($p < 0.0001$). In some cases, an increase in inclination was the only radiographic sign of acetabular component migration. Therefore, this parameter may be considered an independent risk factor for the progression of migration. The biomechanics of these phenomena were described by A.T. Phillips et al. [42].

Radiolucent lines were identified in 7 (16.7%) cases in our study. In six of these, the lines were confined to a single zone. The HHS values in this subgroup exceeded 74 points; therefore, these radiographic findings were not classified as failures in the survivorship analysis. M.J. Willson et al. also reported the presence of radiolucent lines at the prosthesis-bone interface in clinically well-functioning joints [43]. As previously demonstrated, classical radiographic signs of aseptic loosening may not always be evident against the background of ongoing compaction of morselized bone graft under cyclic loading [18]. Accordingly, the acetabular component migration observed in our study in 24 cases (57.1%) did not always present with radiographic indicators of aseptic loosening, and conversely, the presence of such markers did not consistently reflect the clinical picture. The signs of loosening often became apparent only in cases where the acetabular component migrated beyond the anatomical acetabulum (3 cases) or when implant failure occurred with screw migration (1 case). Moreover, the interpretation of radiographic images was often complicated by overlapping shadows from reconstruction hardware superimposed on the graft mass or the acetabular component itself. Thus, in the evaluation of outcomes following IBG, the interpretation of radiological data in conjunction with clinical findings remains a critical aspect. In our cohort, the functional outcomes were classified as good to excellent based on the HHS and WOMAC scores, with a median of 85.5 (95% CI: 70.5-95.0) and 6.5 (95% CI: 2.0-21.0) points, respectively, which is consistent with the findings of other recent studies [16, 17, 35].

A distinctive feature of this study was that 21 patients (50%) available for follow-up presented with the most severe reconstruction challenges: type 3B acetabular defects according to Paprosky. The limited form of these defects created the most favorable conditions for retaining the bone graft material. This served as a selection factor for determining indications for IBG at the preoperative stage. The preserved contour of the compact bone of the acetabular region provided optimal support for graft containment. As demonstrated by our data and the findings of a systematic review by M.A. Malahias et al. [44], the use of various meshes for augmentation in segmental defects was associated with more frequent or pronounced migration of the acetabular component in massive defects, suggesting the consideration of alternative technologies when extensive meshes or multiple constructs are required for defect containment.

P. Cimatti et al., in their meta-analysis, reported high survivorship rates of different implant types used with IBG over an average follow-up of 9.2 years. Cemented cups, uncemented cups, and anti-protrusio devices showed survivorship rates of 98.45%, 97.91%, and 97.51%, respectively [45]. Thus, in the current era of diverse revision systems and reconstructive approaches for bone defects, the indications for IBG can be more narrowly defined. In our opinion, the optimal application of IBG combined with cemented acetabular components is in cases of strictly limited defects classified as Paprosky types 2A and 3B, and AAOS type II, with preserved acetabular rim and external contour of the compact bone substance, which do not require mesh reconstruction. In such scenarios, we be-lieve that the implantation of metallic augments often necessitates extensive bone preparation and may exacerbate bone loss, whereas IBG represents the optimal reconstructive method.

Study limitations

The limitations of this study include a relatively small number of cases available for final evaluation, as well as the absence of a control group. Comparative analysis remains challenging due to the varying severity of defects and the diversity of implants used for augmentation. Another limitation is the inclusion of patients who underwent primary complex arthroplasty with the use of IBG via the X-Change technology.

CONCLUSIONS

Impaction bone grafting is a method of choice for the reconstruction of limited bone defects in revision total hip arthroplasty, with certain specific features in the interpretation of postoperative X-rays. Subsequent migration of the acetabular component, displacement of the center of rotation exceeding 5 mm along any X/Y axis, and an increase in its inclination within 10° correspond to a conditional norm and are associated with natural biomechanical processes occurring in the impacted cancellous bone. The consistency of these processes is confirmed by good and excellent clinical outcomes at the study endpoint: HHS — 85.5 [70.5; 95.0] points, WOMAC — 6.5 [2.0; 21.0] points. Revealed strong direct correlation ($p = 0.006$) between migration of the acetabular component in type III defects by AAOS and grade 3B by Paprosky with the use of any mesh type on the acetabular rim does not indicate the development of aseptic loosening of the acetabular component. This is supported by the midterm overall prosthesis survival estimated by Kaplan-Meier analysis for revision and complex primary total hip arthroplasty using impact bone grafting, which was 97.9% at 60 months and 84.3% at 90 months.

DISCLAIMERS

Author contribution

Golnik V.N. – treatment of patients, data interpretation, drafting and editing the manuscript.

Ivanyuk A.M. – treatment of patients, data interpretation.

Dzhukhaev D.A. – treatment of patients, data interpretation.

Zolovkina A.G. – statistical data processing, editing the manuscript.

Korenyak N.A. – data acquisition and processing, editing the manuscript.

Batrak Yu.M. – data processing and analysis, drafting the manuscript.

Peleganchuk V.A. – scientific guidance, editing the manuscript.

Pavlov V.V. – study concept and design, editing the manuscript.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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