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Revision Hip Arthroplasty with Initially High Position of the Acetabular Component: What's Special?

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Abstract

Background. Total hip arthroplasty with a severe dysplasia refers to complex cases of replacement. One of the options for fixation of the acetabular component in this situation is to place the cup in the false acetabulum. Revisions in case of the acetabular component initial placement into the false acetabulum are highly complex. ***The purpose*** — was to study the features of revision hip arthroplasty in the patients with dysplastic arthritis and loosening of the acetabular component initially placed in the false acetabulum. ***Materials and Methods.*** The clinical and functional results and complications were evaluated after 44 revisions performed by one surgical team from 2001 to 2019. How the position of acetabular component vertical and horizontal centers of rotation after primary arthroplasty influenced the long-term survival of implants was analyzed. The degree of impact of the preoperative cranial displacement from the anatomical location of the femoral component center of rotation impact on surgical tactics was also investigated. ***Results.*** A combination of a highly porous cup with augment was used most frequently for acetabular component replacement (24 cases; 54.5%). Complications after the revision were detected in 6 (13.6%) patients. The values of the Oxford Hip Score, EQ-5D, VAS general health, and VAS pain depended on the postoperative position of the hip prosthesis center of rotation within 10 mm from the anatomical center. The odds ratio for the revision performed less than 10 years after the primary arthroplasty in the patients with a horizontal position of the center of rotation of 40 mm or more was equal to 14.571 (95% CI from 1.682 to 126.249; $p = 0.011$). The average value of the distal displacement of the center of rotation after the surgery was 32.0 mm (min-max 4.7 to 90.3 mm; Me 23.9 mm), the average residual displacement of the center of rotation after the surgery was 6.2 mm (min-max 10.8 to 32.1 mm; Me 4.75 mm). The standard approach was characterized by a lesser distal displacement of the center of rotation than various osteotomy options: 26.1 mm (min-max 4.7 to 77.2; Me 19.1 mm) vs 41.2 mm (min-max 10.8 to 90.3 mm; Me 36 mm), respectively ($p = 0.021$). A well-fixed stem preservation resulted in the mean distal displacement of the femur of 23.8 mm, the stem removed — of 35.0 mm. ***Conclusion.*** A horizontal center of rotation displacement of 40 mm or more affects the long-term survival of the implant. When the significant lowering of the femur is required (more than 30 mm) and a well-fixed femoral component is preserved, it is advisable to use the approach with extended trochanteric osteotomy or shortening femoral osteotomy. The acetabular component placement into the true acetabulum with weakened bone requires extended screw fixation. In this situation the use of individual 3D-printed implants has potential benefits.

Keywords: revision hip arthroplasty, hip dysplasia, high center of rotation, osteotomy, individual implants.

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The majority of researchers associate the difficulties of hip arthroplasty (HA) in developmental dysplasia of the hip (DDH) with the severe anatomical impairment of both the acetabulum and the femur, as well as significant limb shortening [1, 2, 3, 4, 5, 6]. One of the options for a compromise solution in severe DDH is the cup placement in the so-called "high" position. This makes it possible to avoid the excessive lengthening of the limb and to improve the conditions for fixing the acetabular component [2, 7, 8, 9, 10]. At the same time, most publications emphasize the importance of placing the acetabular component strictly in the anatomical position due to a larger percentage of the loosening of the cups placed high or the pronounced biomechanical impairment and weakness of the abduction apparatus [3, 11, 12, 13]. However, the understanding of the "anatomical position" itself presented in the literature is rather variable. According to M.W. Pagnano et al. initially considered cranial and lateral displacement within 10 mm from the approximate anatomical center of rotation as acceptable [14]. Subsequently, the same group of the authors expanded the permissible limits to 15 mm from the approximate anatomical center of rotation or within 35 mm from the line connecting the "teardrop figures" [15], as was proposed for revision HA [16]. Much more often, authors do not specified at all from what value the cranial displacement should be considered as high [10, 17, 18, 19].

There are isolated publications that clearly show more frequent loosening of the acetabular component in its cranial displacement [14]. Most authors point out the danger of lateral or upper-lateral cup placement [20, 21]. Moreover, there are many works demonstrated the outstanding values of cup survival up to 10 to15 years [9, 20, 22, 23, 24, 25] due to the increase of the acetabular component contact area with the bone during its cranial displacement [26, 27]. In addition, modern studies indicate the absence of gait impairment in the DDH patients with the high location of the acetabular component [28]. Nevertheless, the revisions, when the cup was initially placed at the "false" acetabulum, are highly complex [29]. They have several important points for the surgeon: the quality of bone tissue assessment, the optimal placement of the acetabular component, the rational access, and the position in relation to a well-fixed femoral component.

The purpose of this study was to explore the features of revision HA in the patients with DDH in whom the acetabular component loosening developed after the cup was initially placed in the false acetabulum.

The study posed the following questions: does the acetabular component survival depend on the magnitude of the cranial displacement; whether it is always necessary to replace the acetabular component into the anatomical position; is it always possible to accomplish the surgery with "standard" revision constructions; what access is optimal in case of a possible change in the surgery plan?

Materials and Methods

Design: this was a cohort retrospective cross-sectional study.

Inclusion criteria: the revision was performed due to loosening of the acetabular component placed at the false acetabulum during the primary HA in the patients with DDH.

Patients. 41 patients (3 men and 38 women) with DDH underwent revision HA by one surgical team at the Vreden National Medical Research Center of Traumatology and Orthopedics, St. Petersburg, Russia, over the period from 2001 to 2019. In total, 44 revisions were performed (3 patients were operated on both sides). The average patients age at the time of the revision was 61.1 years (from 35 to 82). In 13 cases (29.5%) the revisions had already been performed, of which in 4 cases it was the spacer placement for prosthetic joint infection (PJI). The time from the primary HA to the 1st revision varied dramatically, from 1 to 33 years, mean 10.4 years (95% CI 8.2 to 12.7 years, Me 8 years).

The revision results were assessed in all patients (44 operated joints) in the period from 1 to 18 years. One female patient died in 13 years after the revision for reasons not related to the surgery.

The method of X-ray analysis. The X-ray measurements were carried out using the Weasis 2.0.3 software (free access). The anatomical center of rotation was determined for each case by the Ranawat method [30] (Fig. 1) and its vertical and horizontal positions were assessed.

The scaling of the plain pelvis X-rays for determination of the vertical and horizontal displacement of the placed acetabular component center of rotation was carried out using the known diameter of the endoprosthesis head. The vertical position of the center of rotation was determined from the center of rotation of the acetabular component to the line connecting the "teardrop figures". The value of the horizontal position of the center of rotation was equal to the distance between two perpendiculars drawn through the hip center of rotation and the apex of the "teardrop figure" to the line connected the "teardrop figure" (Fig. 2) [31].

In case of acetabular component displacement due to loosening, an additional computer simulation was performed with the movement of the virtual cup of the corresponding diameter to its initial position (visualized on X-rays in 100% of cases). In such cases, the position of the center of rotation after the initial HA and the position of the center of rotation resulting from the cup displacement were evaluated separately (Fig. 3).

To understand the required lengthening of the limb during the revision and to determine the required amount of distal displacement of the center of rotation, the value of its cranial displacement was assessed. The cranial displacement was defined as the distance from the center of the femoral component head to the anatomical center of rotation, since in some cases the centers of rotation of the acetabular and femoral components were not coincide due to dislocation or penetration of the head into the polyethylene liner. After the surgery, the residual cranial displacement of the center of rotation was determined.

Acetabular bone defects were assessed according to W. Paprosky's classification.

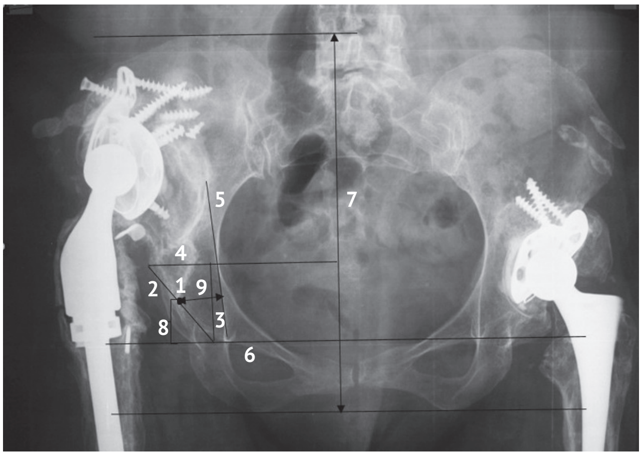

Figure 1. Technique for determining the center of rotation by Ranawat. The true center of rotation (1) is located in the center of the hypotenuse (2), which connects the end points of the perpendicular (3) and parallel (4) lines. The perpendicular line is drawn 5 mm from the Kohler line (5) and is perpendicular to interteardrop line (6). A parallel line is drawn above the interteardrop line at a distance equal to 20% of the entire height of the pelvis (7). The vertical (8) and horizontal (9) rotation centers are equal to the distance from the true rotation center to the interteardrop line and the Kohler line respectively.

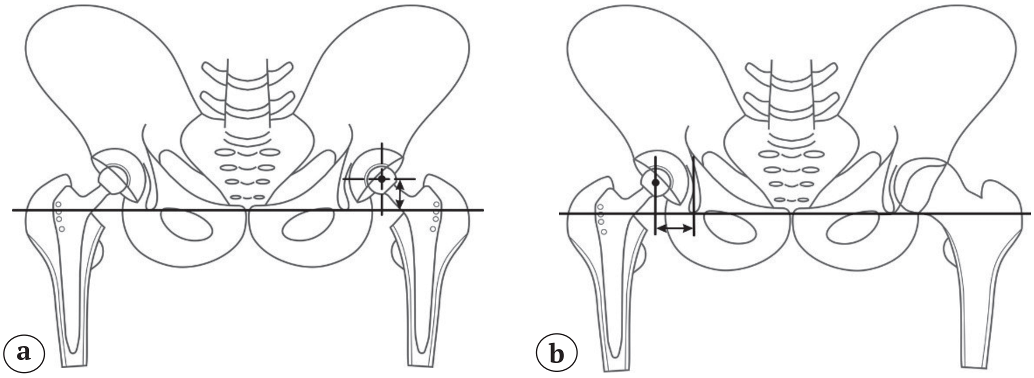

Figure 2. The scheme of the acetabular component center of rotation determination on the direct X-ray: a — vertical; b — horizontal [31].

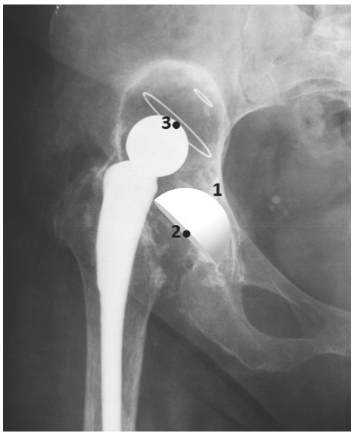

Figure 3. The computer modeling of the center of rotation after primary hip arthroplasty:
1 — virtual cup; 2 — the position of the acetabular component center of rotation after the primary arthroplasty; 3 — the position of the acetabular component center of rotation as a result of displacement.

Assessment of the results

The Oxford Hip Score, the EQ-5D quality of life measure, the general health VAS, and the pain VAS were used for the clinical and functional assessment of the results.

Statistical analysis

The statistical processing was performed using the Past 3.14 software. For quantitative data after checking for the distribution normality, the parametric Student's test and the nonparametric Mann-Whitney test were used. For qualitative data, a set of nonparametric criteria was used: $\chi 2$, $\chi 2$ with Yates' correction, and Fisher's test. We also calculated the odds ratio (OR) with 95% CI.

Results

X-ray analysis

The true center of rotation was located on average at 19.7 mm vertically (min–max 14.8–26.7 mm; Me 19.3 mm) and 24.7 mm horizontally (min–max 19.9–30.6 mm; Me 24.6 mm). The initial vertical position of the center of rotation after the primary HA was 45.7 mm on average (min–max 27.1–67.4 mm; Me 43 mm). The initial horizontal position of the center of rotation averaged 36.2 mm (min–max 24.1–57.2 mm; Me 35.6 mm). No significant correlation was found between the vertical and horizontal displacement and the period from the primary HA to the 1st revision. But in the case of pronounced center of rotation lateralization, the risk of revision significantly increased during the first 10 years. In our study, the horizontal position of the center of rotation of more than 40 mm resulted in the situation when only 1 endoprosthesis survived for more than 10 years, and 12 were revised in a period from 1 to 8 years. Conversely, in less lateralization, 17 endoprostheses survived for 10 or more years, and the revision was carried out at an earlier term in 14 cases. The OR for revision in terms of less than 10 years for the horizontal position of the center of rotation of 40 mm or more was 14.571 (95% CI 1.682–126.249; p = 0.011). The vertical position of the center of rotation did not have such an impact on the long-term endoprosthesis survival. Its average value in the patients with the revision term from 1 to 9 years was 46.6 mm (min–max 27.1–63.6 mm; Me 45.3 mm), and with the revision term from 10 years or more – 44.5 mm (min–max 30.7–67.4 mm; Me 44 mm); p = 0.34. Thus, according to our data, the horizontal position of the center of rotation more than 40 mm during HA in in the patients with DDH negatively affected the long-term survival, in contrast to the position of the vertical center of rotation.

Surgical technigue

The cranial displacement of the center of rotation during the endoprosthesis functioning increased due to the acetabular component loosening, as well as subluxation or dislocation of the head in 23 of 44 cases (52.3%). As a result, the cranial displacement of the center of rotation from the true center of rotation before the revision was 38.1 mm on average (min–max 13.5–88.0 mm; Me 35.9). In all cases, there were severe defects in the acetabular bone tissue: in 38 cases – type 3A (86.4%), in 3 cases – type 3B (6.8%), and in 3 cases – type 3B with the signs of pelvic ring disruption (6.8%).

The surgery was performed through the standard Harding approach in 27 (61.4%) cases. The extended femoral osteotomy was used to remove the femoral component in 7 (15.9%) cases. The combination of the femoral component removal with the femur shortening osteotomy and distal movement of the greater trochanter fragment (similar to the Paavilainen operation) was employed in 10 (22.7%) cases. The most often operation to replace the acetabular component was the combination of a highly porous cup with an augment (24 cases, 54.5%), including in 6 (13.6%) cases with customized augments. In 12 (27.3%) cases, only a multi-hole hemispherical cup was used, in one (2.3%) case – a cup-cage, and in 7 cases (15.9%) – a triflange customized implant. The bone grafting with allografts was used in 7 (15.9%) patients and in one (2.3%) case – a massive allograft (Table 1).

During the revision, the magnitude of the distal displacement of the center of rotation varied significantly (from −4.7 mm to +90.3 mm) depending on the surgical approach, preservation or replacement of the femoral component, and the acetabular implants used. The average value of the distal displacement of the center of rotation was 32.0 mm (min–max from −4.7 to +90.3 mm; Me 23.9 mm), the average residual displacement of the center of rotation after surgery was 6.2 mm (min–max from −10.8 to +32.1 mm; Me 4.75 mm). There was no statistically significant difference in the initial cranial displacement of the center of rotation between the observations with the standard approach and with the extended femoral osteotomy or shortening osteotomy with distal movement of the greater trochanter (Paavilainen type), p = 0.173. However, when the standard approach was employed, a smaller distal displacement of the center of rotation was noted in comparison with various osteotomy options, namely −26.1 mm (min–max from −4.7 to +77.2 mm; Me 19.1 mm) and 41.2 mm (min–max 10.8–90.3 mm; Me 36 mm), respectively; p = 0.021. This resulted in a greater average residual displacement of 9.0 mm (min–max from −5.9 to +32.1 mm; Me 10.3) compared with 1.6 mm (min–max from −10.8 to +30.7 mm; Me 1.6 mm); p = 0.023.

The OR for maintaining residual cranial displacement of the center of rotation using the standard approach in comparison with the osteotomy was 2.857 (95% CI 0.815 to 10.015), p = 0.178.

The femoral component loosening before revision was observed in 9 (20.5%) cases, and in another 3 (6.8%) cases an articulating spacer was previously installed for PJI. In 30 (68.2%) cases, the femoral component was well fixed, however, it was preserved only in 12 of them (40%). In other cases, the femoral component removal was required due to a significant cranial displacement of the hip center of rotation. Thus, the femoral component replacement was performed in 32 (72.7%) cases. To replace the femoral component, the Wagner conical and revision stems were most often used: in 14 (43.8%) and 11 (34.4%) cases, respectively. The standard and revision versions of the Zweymüller stems were used much less frequently: 4 (12.5%) and 3 observations (9.4%), respectively.

Clinical and functional results and complications. According to the Oxford Hip Score questionnaire, the functional status of our patients at the time of their examination varied within the range of possible values from 12 to 48 points, with the mean value being 35.4 points (min–max 12–48; Me 36 points). We could not detect the dependence of the clinical and functional results on the degree of distal displacement of the center of rotation.

The values of the Oxford Hip Score, EQ-5D, general health VAS, and the pain VAS demonstrated dependence on the positioning of the center of rotation of the hip endoprosthesis in the postoperative period within 10 mm from the anatomical center of rotation and cranially 10 mm from the anatomical center of rotation (Table 2).

Table 1

The cranial displacement of the center of rotation at the time of revision and the possibility of its restoration depending on surgical techigues

Surgical technology	Preservation of the femoral component	Removal of the femoral component			Total
		Standard approach	Extended femoral osteotomy	Shortening osteotomy Paavilainen type	
Hemispherical cup with multiple screws	3 (6.8)	7 (15.9)	–	2 (4.5)	12 (27.3)
	24.7	28.4	–	62.4	34.4
	20.9	13.7	–	70.7	24.8
	3.9	14.7	–	−8.3	9.7
Augment and hemispherical cup	6 (13.6)	4 (9.1)	7 (15.9)	7 (15.9)	24 (54.5)
	34.1	34.6	38.6	38.6	36.8
	26.1	22.9	36.7	33.8	30.9
	8.7	11.7	1.9	4.8	5.9
Cup-cage system	1 (2.3)	–	–	–	1 (2.3)
	35.6	–	–	–	38.3
	19.8	–	–	–	19.8
	15.8	–	–	–	18.5
Triflange customized implant	2 (4.5)	4 (9.1)	–	1 (2.3)	7 (15.9)
	31.8	54.8	–	62.9	49.4
	23.1	57.9	–	66.1	49.7
	8.7	−3.1	–	−3.2	−0.3
Total	12 (27.3)	15 (34.1)	7 (15.9)	10 (22.7	44 (100)
	31.5	36.8	38.6	45.8	38.1
	23.8	25.1	36.7	44.4	32.0
	7.8	11.6	1.9	1.4	6.2

Table 2

Dependence of clinical and functional results on the positioning of the center of rotation

Scale	p	Position of the center of rotation, mean/Me (min–max)	
		within 10 mm	proximal to 10 mm
Oxford Hip Score	0.08	37.6/Me 37 (22–48)	32.2/Me 30 (12–46)
EQ-5D	<0.05	0.67/Me 0.59 (0.49–1.00)	0.55/Me 0.52 (–0.04 to +1.00)
General health VAS	<0.05	75.2/Me 70 (50–100)	64.1/Me 70 (30–90)
Pain VAS	0.06	15.6/Me 10 (0–40)	29.4/Me 20 (0–80)

There was a correlation between the patients' age and the degree of their satisfaction with the results of the surgery; R = 0.413; p = 0.01. Older patients were generally more satisfied with the treatment outcome.

Complications were detected in 6 (13.6%) patients: in 3 cases – the loosening of the cup, in 2 – the recurrent dislocation of the hip, and in one – the relapse of PJI. All patients underwent surgical treatment, which included the replacement of the acetabular component in 3 cases, the placement of a dual mobility system (for hip dislocations) in 2 cases, and two-stage surgical debridement of the infected joint in 1 patient.

Discussion

The position of the acetabular component in the patients with severe DDH remains one of the most discussed [9, 32]. Those who support the placement of the center of rotation into the area of the true acetabulum believe that the main advantages of this technique are restoration of normal biomechanics, optimal range of motion, and better endoprosthesis survival rates [33, 34, 35]. However, literature data [36, 37] and our study did not reveal a relationship between the survival time and the degree of cranial displacement.

The surgical management of the loosening of previously highly placed acetabular components is challenging for several reasons. 86.4% of the patients had acetabular defect 3A, 6.8% – 3B, and 6.8% – 3B with pelvic ring disruption. However, unlike the classic 3A defect associated with osteolysis of a correctly placed cup, the loosening of the implant placed in the false acetabulum leads to greater bone loss, progressive cranialization of the femur, while the distally located true acetabulum is characterized by rudimentarity, pronounced osteoporosis, although with bone vitality preservation. Therefore, the main task in planning the surgery is to determine the optimal position of the acetabular component, which provides maximum contact with the preserved bone tissue in order to achieve secondary osseointegration. In 12 patients, this was achieved by using highly porous multihole cups with filling of the cavitary defects with bone allografts. The trabecular metal revision cups have certain advantages due to the possibility of forming additional holes and installing dual mobility systems on cement. Our experience has shown that it is not always necessary to place the cup in a strictly anatomical position. The optimal position is often determined by the surgeon during the operation. Nevertheless, the average value of the residual proximal displacement of the center of rotation from the anatomical after revision was only 6.2 mm.

The second important question is how to replace the acetabular defect and create a good end stop for the cup? The use of massive allografts in the long-term period is accompanied by the loss of their mechanical properties and their loosening. The use of support rings does not make it possible to achieve the osseointegration which again leads to the implants loosening. The optimal choice in the conditions of compromised bone tissue is the use of metal highly porous augments. We used them in 54% of cases. The complex relief of the acetabular defect, an extremely limited supply of the preserved bone tissue, and modern visualization and 3D modeling capabilities make it appropriate to refer to customized augments, which were used in 13.6% of cases. As can be seen from the above results, the new center of rotation was located distally to the previously established during primary HA by an average of 32 mm (fluctuations ranged from –4.7 to +90.3 mm). The mean distal displacement of the femur was 23.8 mm in the condition of well-fixed stem. When the stem was removed, it became 35.0 mm. The femoral component replacement is necessary to lower the center of rotation by more than 25–30 mm. This creates some additional difficulties during the surgery and makes rehabilitation longer.

Of particular difficulty are patients with type 3B defect and 3B in combination with signs of pelvic ring disruption. A small number of observations and the pronounced heterogeneity of anatomical changes do not allow for a full analysis of the results. However, even a small number of operations for this pathology indicates the need to use more complex structures of the acetabular component. We used in 4 cases the customized implants and in 1 case – a cup-cage and a trabecular metal revision cup in combination with two augments.

The main purpose of our work was to show the technical features of the revisions with a high cup position. This made it impossible to compare the results before and after the surgery due to the retrospective study design. However, the functional data strongly depended on the position of the hip center of rotation. The optimal allowable level of proximal displacement was 10 mm. The factor of preserving or replacing the stem as such did not have a strong influence. The position of the center of rotation was more important.

The study format does not allow us to comment on how often the placement of the acetabular component into the false acetabulum leads to loosening in comparison with the placement into the anatomical position. According to our data, the average time to the first revision was 8.2 years. However, it can be unambiguously concluded that in case of DDH of type C2 by Hartofilakidis, placing the cup in the false acetabulum leads to rapid loosening, and the high position of the center of rotation creates additional technical difficulties due to the bone tissue deficit and the high position of the endoprosthesis stem. One example is the following clinical case.

A 46-year-old female patient came to the clinic for pain and severe dysfunction of both hip joints. From the anamnesis: primary HA for DDH (type C2) was performed sequentially 1.5 and 1 year ago. A few months after the surgery, the aforementioned complaints appeared, which were the reason for the hospitalization. The analysis of the presented X-rays showed the following: the endoprosthesis cup on the left was initially placed in the false acetabulum (this can be seen from the remains of cement) with a shift of the center of rotation from the true upward and laterally by 22.8 and 3.4 mm, respectively. At the time of hospitalization, there was a further displacement of the cement cup in the cranial direction, and the difference between the true center of rotation and the center of the endoprosthesis head was already 58.3 mm (Fig. 4).

After 3D reconstruction of the acetabulum (Fig. 5 a, b) and assessment of the bone tissue conditions, the plan of the surgery included placement a customized flange cup in the anatomical position (Fig. 5 c), while the distal displacement of the existing center of rotation should be 58.3 mm.

Considering the time elapsed after the previous surgery, the need for large distalization of the hip and the state of soft tissues, it was decided to replace the femoral component with a 46.2 mm shortening of the hip. An attempt to lower the greater trochanter during the surgery was unsuccessful due to pronounced scars (Fig. 6).

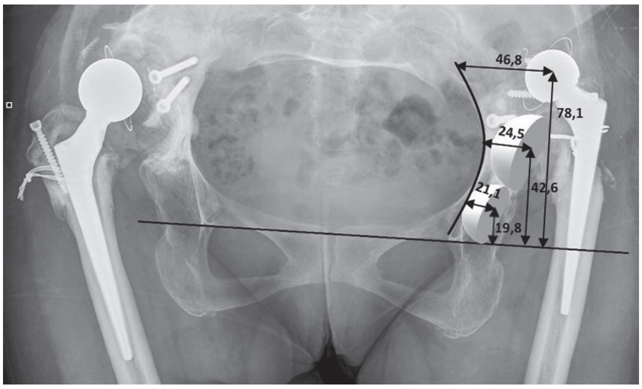

Figure 4. The values of the planned, primary and actual vertical and horizontal centers of rotation in mm on the frontal X-ray of a 46-year-old female patient.

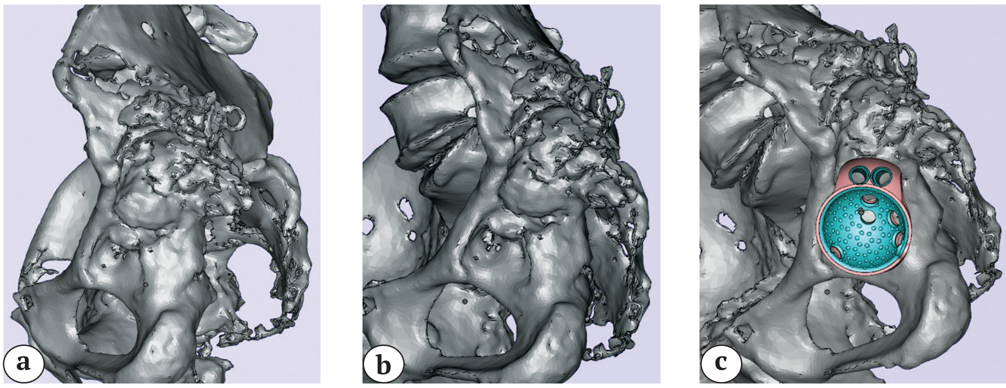

Figure 5. The stages of 3D planning of the revision arthroplasty for a 46-year-old female patient: a, b — reconstruction of the pelvis; c — plan of the individual design implantation in the anatomical position.

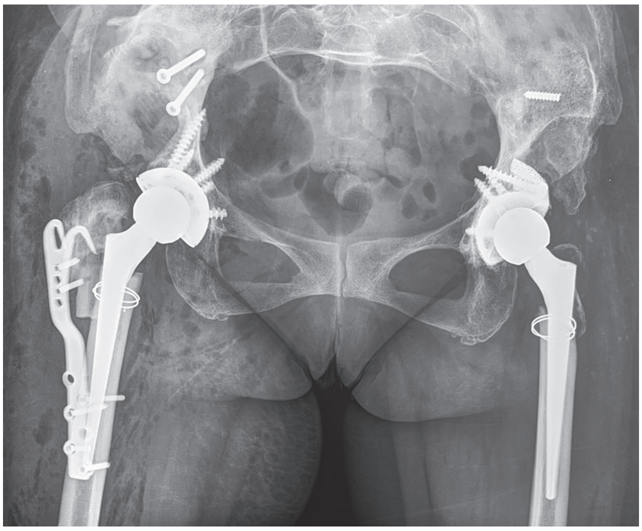

Figure 6. The frontal X-ray of a 46-year-old female patient the day after the revision.

A similar operation was performed on the right hip in June 2020 (this observation was not included in the study). The reason for such a complex revision was the cup placement in the false acetabulum with a compensatory high position of the femoral component.

Thus, with all the attractiveness of placing a cup in a false acetabulum during primary HA for severe DDH, it is necessary to understand that possible revisions will be accompanied by significant technical difficulties. If a significant lowering of the femur is required (more than 30 mm) with the presence of a well-fixed femoral component, it is advisable to use an approach with an extended trochanteric osteotomy or a shortening femoral osteotomy. The placement of the acetabular component into the true acetabulum against a weakened bone background requires extended screw fixation. Thus, the use of customized 3D-printed implants has potential benefits.

Consent

The patients gave a voluntary informed consent for the participation in this study and publication of clinical cases.

Competing interests: The authors declare no conflict of interest.

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Authors' contributions

R.M. Tikhilov – research conception and design, data interpretation and analysis, text editing.

A.A. Dzhavadov – collection and processing of material, research conduction, data statistical processing, text preparation.

A.S. Karpukhin – collection of material.

A.G. Vahramyan – data analysis and interpretation, text editing.

K.A. Demyanova – literature review.

I.I. Shubnyakov – coordination of study participants, data interpretation and analysis, data statistical processing, text editing.

All authors made a significant contribution to the research and preparation of the article and read and approved the final version before its publication. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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