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Comparative Assessment of Subtrochanteric Shortening Osteotomy and Paavilainen's Proximal Osteotomy in Total Hip Arthroplasty for Crowe III–IV Dysplasia

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Abstract

The purpose of the study — to compare the results of the subtrochanteric shortening osteotomy and Paavilainen proximal osteotomy in the total hip arthroplasty for Crowe III and IV dysplasia. ***Material and Methods.*** It was performed 36 hip arthroplasties in the patients with Crowe III (12) and IV (24) dysplasia. Two methods of the shortening osteotomy were used: Paavilainen osteotomy (22) and subtrochanteric osteotomy (14). The average follow-up was 42.3±22.7 months (from 6 to 88). Among the patients, there were 25 (75.8%) women and 8 (24.2%) men with the average age of 51.5±13.1 and 34.6±20.4 years, respectively. ***Results.*** The lateral acetabular deficiency required the structural repair of the femoral head in 16.7% of the cases. The average length of the osteotomized fragment was 56.8±16.3 mm, the caudal displacement of the greater trochanter apex — 47.0±15.6 mm, the limb lengthening — 30.1±10.9 mm without the statistically significant difference between the groups. The consolidation was achieved on average in 7 months. The Harris score improved on average from 37.6±10.1 points to 76.1±17.6, $p<0.001$ (78.1±15.3 in Paavilainen group and 72.9±20.9 in the subtrochanteric). The overall HOOS score increased from an average of 34.6±12.4 to 74.6±18.6 points, $p<0.001$ (78.1±15.9 in Paavilainen group and 69.1±21.7 in the subtrochanteric). The statistically significant differences between the groups after the surgery were found only in the HOOS pain section. Paavilainen group showed higher scores. Various postoperative complications occurred in 27.8% of cases, 2.4 times more often in the subtrochanteric group. The revision was required in 4 cases out of 36 (11.1%): 2 cases (9.1%) in Paavilainen group and 2 cases (14.3%) in the subtrochanteric. The survival rate of the femoral component throughout the sample was 97.2%. There was only one case of the femoral component replacement in the subtrochanteric group. ***Conclusion.*** Both the subtrochanteric shortening osteotomy and Paavilainen proximal osteotomy have good reconstructive capabilities and sufficient efficacy. We were not able to identify the clear advantages of any of the described options for shortening osteotomy, probably due to the insufficient number of observations. In our practice, we give a preference to subtrochanteric shortening osteotomy of the femur.

Keywords: hip dysplasia, total hip arthroplasty, subtrochanteric shortening osteotomy, Paavilainen proximal osteotomy, high hip dislocation.

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Hip dysplasia (HD) is an abnormal development of the joint accompanied by anatomical changes in the acetabulum and femur [1, 2]. In this disease the acetabulum and femoral head are incongruent, that contributes to hip dislocation [3]. Dysplasia is the most common cause of hip osteoarthritis. There are two secondary HD disorders: the lumbar region hyperlordosis with bilateral hip dislocation and compensatory knee valgus deformity [4, 5].

The definitive treatment for Crowe III and IV HD is total hip arthroplasty (HA). Anatomical changes in severe HD results in the following surgical problems: retroversion of the acetabulum with decrease of its depth, the proximal location of the femur, which can form a false acetabulum, bone tissue and abducent muscles deficiency, difference in the limbs length, femoral head deformation, shortening of the femoral neck with excessive anteversion, and medullary canal narrowing [6, 7].

To date, there is no single strategy for HA in severe HD. The goals of the surgery in severe HD are bringing down the femoral head into the true acetabulum, muscle balance restoration, limb length alignment as much as possible [8].

The restoration of the true center of hip rotation, especially in high HD or the presence of cicatricial changes in the periarticular tissues after previous surgery, can lead to excessive lengthening of the lower extremity by more than 4 cm, soft tissues tension, including muscles and tendons, abductors dysfunction, hip stiffness, neurological and vascular structures overexertion with sciatic nerve neuropathy, endoprosthesis components early loosening [9, 10, 11]. To reduce the likelihood of these total HA complications, various options of the femur shortening osteotomy are performed [9]. The most commonly used are the postoperative subtrochanteric shortening osteotomy (STSO) and Paavilainen's proximal osteotomy (PPO) [8, 12, 13]. In the literature, we did not find any publications comparing the results of both the above mentioned options.

The purpose of the study is to compare the results of postoperative STSO and PPO total HA in the patients with Crowe III and IV HD.

Material and Methods

Study design: retrospective, single center, cohort.

38 patients (42 surgeries) underwent shortening osteotomy from 2012 to the beginning of 2019. We evaluated the results of 36 arthroplasties in 33 patients. The remaining 5 patients were not available to follow-up. Thus, the treatment results were tracked in 87.8% of cases.

The study included 25 (75.8%) women and 8 (24.2%) men with average age of 47.3±16.7 years (from 15 to 76). Taken separately, the men's average age was 34.6±20.4 years and women — 51.5±13.1 (p = 0.039). The PPO was performed in 22 cases, the STSO — in 14 cases. The results of all 36 surgeries were tracked in the period from 6 to 88 months, the average follow-up was 42.3±22.7 months.

The surgical technique. We used the surgical techniques that differed from the original in some detail. In PPO, in most cases, if possible, we preserved the muscle vastus lateralis attachment point. If it was necessary (for example, in the case of a greater trochanter short fragment) we separated the muscle from the greater trochanter only partially. According to the original method, the standard procedure for the osteotomized greater trochanter fragments fixture includes the use of wire cerclage and two 3.5 mm cortical screws. For the large trochanter fixation, we used wire or cable cerclage. Usually, it was 2 units, infrequently — 3 to 4 units. We used screws only when it was absolutely necessary. In our opinion, for reliable fixation of the greater trochanter osteotomized fragments, the use only cerclages was enough.

This allowed for reduction the degree of injury, minimizing the likelihood of complications associated with screws loosening or intraoperative fractures due to the screws insertion (Fig. 1).

The STSO was mostly performed by the standard procedures. In some cases, we additionally reinforced the contact area of the proximal and distal femoral fragments with autograft fixed by cerclage sutures (Fig. 2).

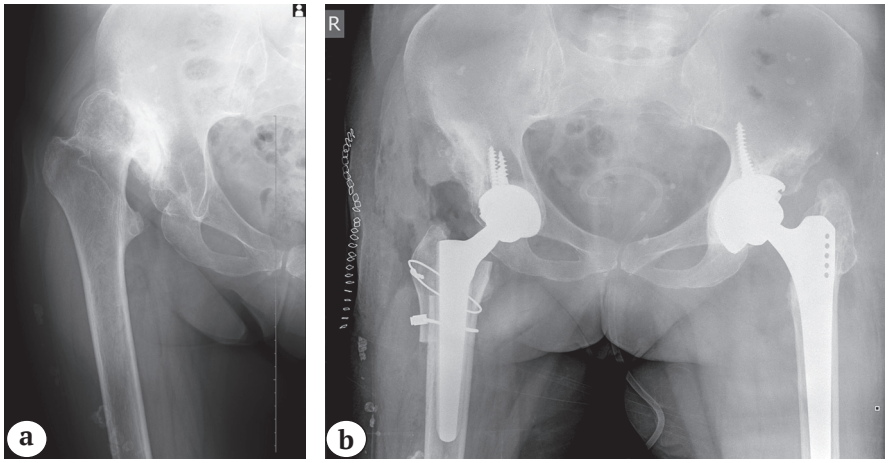

Fig. 1. X-rays of the pelvis of the 66-year-old patient with bilateral Crowe IV hip dysplasia:
a — before the surgery;
b — immediately after the right total hip arthroplasty with Paavilainen's shortening osteotomy without screws for the fixation of the greater trochanter osteotomized fragments

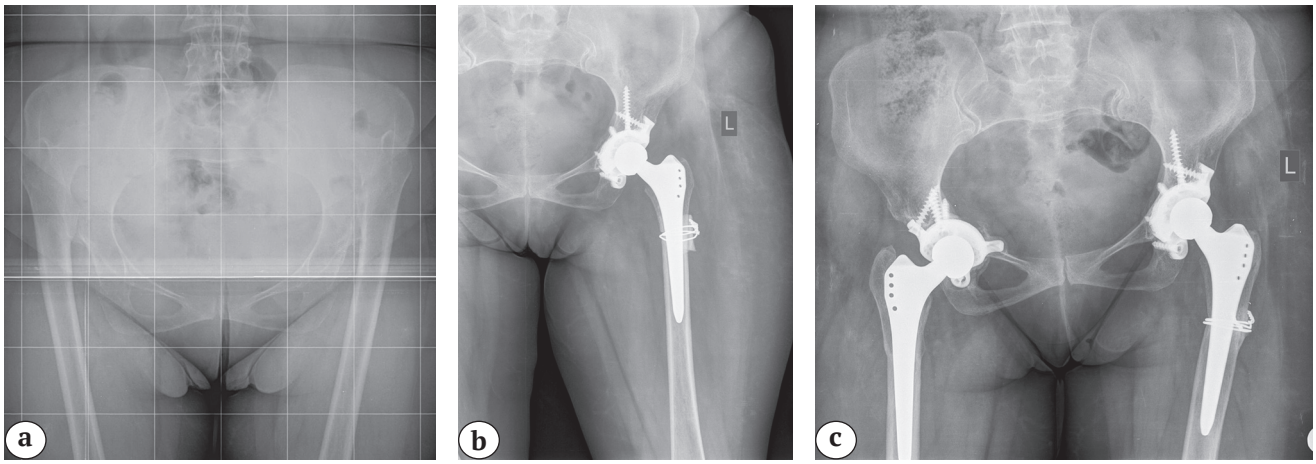

Fig. 2. X-rays of the pelvis of the 44-year-old patient with bilateral Crowe IV hip dysplasia:
a — before the surgery;
b — in 3 months after the left total hip arthroplasty with the subtrochanteric osteotomy and additional reinforcement of the femur proximal and distal contact area with an autograft;
c — in 18 months after the left total hip arthroplasty (12 months after the right total hip arthroplasty)

The degree of HD was determined according to the generally accepted J.F. Crowe classification [14]. The HD of the III stage was established, in 12 patients, the HD of the IV stage — in 24. We believe that the use of the Hartofilakidis classification [15] in such cases is more convenient. This classification permits the division of a high hip dislocation into types C1 and C2, which allows one to take into account the anatomical features of the relationship between the acetabulum and the femoral head and to determine in advance some detail of the forthcoming operation. Unfortunately, we were not able to apply the Hartofilakidis classification due to the inability to perform computed tomography for all the patients.

In 18 (54.5%) patients, the pathological process affected one hip, in 15 (45.5%) HD was bilateral. Three patients out of 33 underwent sequential total HA with shortening osteotomy on both sides (after 2.5 months, 8.5 months, and 1 year and 7 months). In the remaining 30 patients, the surgeries were distributed equally between the right and left joints — 15 on each side. The average relative shortening of the lower limb (excluding cases with bilateral dislocation) was 47.7±18.4 mm (32 to 71).

In 22 (61.1%) cases, HA was the first surgery on the hip. In the remaining 14 (38.9%) cases, 13 surgical patients had a history of various hip surgery (open reduction of dislocations, hip osteotomy), including 5 of them who underwent several interventions (from 2 to 6).

In men and women, the average number of previous hip surgeries differed, namely: 1.9±1.8 and 0.4±1.0, respectively ($p = 0.005$).

In 10 cases, the patients underwent various operations on the contralateral hip (open reduction of dislocations, creation of an additional point of support, total HA, revision HA, hip arthrodesis). Among them, there were 4 patients with a history of 2 to 6 operations on the opposite joint, including 6 patients with contralateral HA.

In all cases, the endoprostheses of cementless fixation were used. In 15 (41.7%) cases, the Trilogy (Zimmer) acetabular components were placed, in 8 (22.2%) — Trilogy IT (Zimmer), in 5 (13.9%) — Pinnacle (DePuy), in 5 (13.9%) — Continuum cup (Zimmer), and in 3 (8.3%) R-3 — (Smith & Nephew).

In all surgeries, the additional fixation of the acetabular component by a screw was required. In 21 (58.3%) cases, 2 screws were required for fixation, in 7 (19.4%) cases — 3 or more screws. It was placed 29 (80.6%) small acetabular components (44–48 mm) and 7 (19.4%) cups with a larger diameter of 50–60 mm. In 3 cases, the individual acetabular constructions made by additive manufacturing were implanted. In all surgeries, the autograft of the acetabular bottom was performed with bone chips. In 6 (16.7%) cases, the structural bone grafting of the acetabulum with the removed femoral head material was required to achieve satisfactory cup coverage.

The most commonly used femoral components were Wagner Cone (Zimmer) conical stems — 26 (72.2%), wedge-shaped stems Alloclassic (Zimmer) — 6 (16.7%), Wagner SL Revision (Zimmer) — 2 (5, 5%), SL-Plus (Smith & Nephew) — 1 (2.8%), and Fitmore (Zimmer) with metaphyseal fixation — 1 (2.8%) case.

In most cases (72.2%), one to three units of wire cerclage or cable were used for the additional fixation of the femoral osteotomized fragments. In 16 (44.4%) cases, only wire cerclage was used, in 6 (16.7%) — only cable. Both types of cerclage was required in 4 (11.1%) surgeries. In 3 (8.3%) cases, the trochanter major was additionally fixed with one, two, or three screws. In 29 (80.6%) HA, the heads with a diameter of 28 mm were placed, and in 7 (19.4%) HA — 32 mm. In 100% of cases, the cup was positioned in the area of the true acetabulum. Most often, the patients were undergone HA with a metal-polyethylene friction pair — 29 (80.6%) cases, less often with a ceramic-ceramic friction pair —

5 (13.9%) cases, and with ceramic-polyethylene pair — 2 (5.5%) cases. A liner with an antiluxation visor was implanted in 16 (44.4%) cases. The average surgery duration was 117±32 min, the intraoperative blood loss was 440±228 ml. At the same time, there was a statistically significant difference in the volume of intraoperative blood loss and the average duration of the operation between the patients with previous hip surgeries and the patients without them — 557.1±277.3 ml and 365.9±156.9 ml, 131.6±37 6 min and 108.0±25.4 min. respectively (p<0.05).

Evaluation of the results

Clinical examination and X-ray were performed before surgery, after 3, 6, 12 months after, and then once a year. A clinical evaluation of the HA results by two different methods of shortening osteotomy was performed according to the Harris Hip Function Scale (HHFS) [16]. To assess the pain intensity, a 10-point *visual analogue scale* (VAS) was used. We also used the *Hip Disability and Osteoarthritis Outcome Score* (HOOS), which is a grading scale for hip function limitation and osteoarthritis outcome. This is is an effective indicator of hip function impairment and associated disorders [18].

Radiological analysis was performed according to survey X-ray of the pelvis before and after HA. The position of the center of rotation of the femoral component head was measured vertically from the line drawn through the "tear shapes" and horizontally from the Keller line. By changing the position of the greater trochanter top relative to the line drawn through the "tear shape", the length of the greater trochanter distal movement was estimated. The extent of the zone of contact of the greater trochanter with the lateral surface of the femur, lengthening the lower limb elongation, the position of the endoprosthesis components, and the degree of consolidation of osteotomized femoral fragments were determined. The radiological difference in the length of the lower extremities before the HA was determined clinically and by comparing the position of the greater trochanters tops in both joints. The relocation of the greater trochanter top did not correspond to the degree of the limb elongation. Therefore, the assessment of the limb elongation was performed by comparing the preoperative and postoperative X-rays. The correction was made for the X-ray magnification by calculating the difference between relocation of the greater trochanter top relative to the line drawn through the "tear shape" and the contact zone of the greater trochanter with the femur [8]. In 72% of cases for a more accurate assessment of the shortening degree, the patients underwent the lower extremities telerentgenograms. The preoperative planning was performed using mediCAD Classic 5.1.0.7 software (mediCAD Hectec GmbH, Germany).

Statistical analysis

Statistical analysis was conducted with Microsoft Office Excel and Statistica 12.0. For descriptive statistics, the data are presented in the form M±SD, where M is the mean value, SD is the standard deviation. The minimum and maximum are shown for some data.

The differences in the comparing groups were assessed by Mann-Whitney U-test for independent groups and the Wilcoxon test for dependent groups. The results of the previous examination were compared with the results of the subsequent. A comparison of the percentages was carried out by Fisher's exact test. Differences between the compared groups were considered statistically significant at p<0.05.

Results

No statistically significant difference was found in gender, age, body mass index, the number of hospital days spent by patients in the hospital, the volume of intraoperative blood loss, the level of hemoglobin and hematocrit when comparing groups with STSO and PPO (Table. 1).

Table 1

Comparative characteristics, anatomical features of the patients, and surgical features of HA for groups STSO and PPO

Indicators	STSO group	PPO group	*p*	Total
Total HA, *n* (%)	14 (38.9)	22 (61.1)	–	36 (100)
Age, years	47.1±20.0	47.4±14.8	0.860	47.3±16.7
Body mass index, kg/m^2	27.6±5,9	26.6±5.1	0.713	27.0±5.4
Bed-days, days	17.0±9.7	14.0±6.2	0.511	15.0±7.8
Pathology side, cases (%)	Unilateral — 6 (42.9)	Unilateral — 12 (54.6)	0,733	Unilateral — 18 (50.0)
	Bilateral — 8 (57.1)	Bilateral — 10 (45.4)	–	Bilateral — 18 (50.0)
HD degree by Crowe, cases (%)	III — 3 (21.4) IV — 11 (78.6)	III — 9 (40.9) IV — 13 (59.1)	0.293	III — 12 (33.3) IV — 24 (66.7)
Concomitant disease, average	2.6±1.6	2.1±2.4	0.049	2.3±2.1
Surgery duration average, min	112.7±33.12	120±32.36	0.431	117.2±32.4
Intraoperative blood loss, ml	496.4±272.1	404.5±194.5	0.296	440.3±228.6
Hemoglobin before / after surgery, g/l	127.6±14.4/ 92.6±14.8	128.8±22.5/ 91.4±17.0	0.413 0.642	128.3±19.5/ 91.9±16.0
Hematocrit before / after surgery, %	39.0±4,1/ 28.6±4.0	38.7±6.9/ 27.8±4.5	0.553 0.642	38.8±5.9/ 28.1±4.3
Caudal relocation of the greater trochanter top, mm (min-max)	52.2±18.3 (20–80)	43.6±12.9 (5–65)	0.116	47.0±15.6 (5–80)
Hip offset from the femur axis to the femoral head center, mm (min-max)	42.2±10.4 (20–56)	43.0±8.4 (20–63)	0.911	42.7±9.1 (20–63)
Osteotomy fragment length, mm, (min-max)	53.8±20.8 (35–100)	58.6±12.8 (40–80)	0.133	56.8±16.3 (35–100)
The extent of the zone of contact of the greater trochanter with the lateral surface of the femur, mm (min-max)	– (Because the osteotomy zone did not run along the greater trochanter)	45.0±14.4 (23–68)	–	–
Limb lengthening after surgery, mm (min-max)	30.6±12.2 (12–41)	29.8±10.3 (18–51)	0.742	30.1±10.9 (12-51)
The cup positioning in the true acetabulum area, cases (%)	14 (100)	22 (100)	–	36 (100)
Follow-up average, months	26.8±14.6	48.8±23.0	0.002	42.3±22.7

In the group with STSO, 3/4 of the patients had high hip dislocation, while in the group with PPO, only in 1/2 of the patients had Crowe IV HD. In the group with STSO, the patients with the previous surgery on the operated hip occurred 1.5 times more frequent, (7 out of 14, 50.0%), than in the group with PPO (7 out of 22. 31.8%).

It was found that in the group with STSO, the average number of concomitant diseases were significantly higher than in the group with PPO. In both groups the common concomitant pathology was presented by cardiovascular and digestive systems diseases and neurological disorders.

In our department, PPO started earlier than the STSO, therefore the average follow-up in the PPO group was 1.8 times longer ($p = 0.002$). Despite more experience, the average duration of surgery in the case of PPO was an average of 8 minutes more than in the case of STSO, although such a small difference was not statistically significant. Of the operational features, it is worth noting the following. In the PPO group, the bone grafting of the acetabulum by the removed femoral head was performed three times more often. While the individually made acetabular components were used exclusively in the STSO group. After the surgery, the relative length of the lower limb increased by 30.1±10.9 mm (from 12 to 51 mm) without a statistically significant difference between the groups. The greater trochanter shifted by 47.0±15.6 mm (from 5 to 80 mm), the offset increased by 7.4±3.9 mm (from 1 to 16 mm).

The results of patients questioning before and after HA using two types of surgery are presented in Table 2.

Table 2

Questioning results of patients before and in 12 months after HA using two comparing methods

Indicators	STSO group	PPO group	*p*	Total
Total HA, n (%)	14 (38.9)	22 (61.1)	–	36 (100)
VAS, before surgery, points	6.1±1.4	6.5±0.9	0,532	6.4±1.1
VAS, after surgery, points	1.4±1.7*	1.0±1.9*	0.296	1.1±1.8*
HHFS, before surgery, points	40.2±9.5	36.0±10.4	0.170	37.6±10.1
HHFS, after surgery, points	72.9±20.9*	78.1±15.3*	0.885	76.1±17.6*
HOOS, Total, before surgery, points	37.5±14.8	32.8±10.6	0.377	34.6±12.4
HOOS, Total, after surgery, points	69.1±21.7*	78.2±15.9*	0.253	74.6±18.6*
HOOS, Symptoms, before surgery, points	41.8±11.2	39.8±10.3	0.665	40.6±10.5
HOOS, Symptoms, after surgery, points	77.5±17.8*	82.7±13.1*	0.311	80.7±15.1*
HOOS, Pain, before surgery, points	46.3±21.1	41.5±15.1	0.490	43.3±17.55
HOOS, Pain, after surgery, points	81.3±21.8*	90.7±18.9*	0.035	87.0±20.3*
HOOS, Activities of Daily Living, before surgery, points	37.8±15.6	31.8±11.6	0.413	34.2±13.4
HOOS, Activities of Daily Living, after surgery, points	69.0±24.1*	77.7±17.5*	0.267	74.3±20.5*
HOOS Sport/Recreation, before surgery, points	20.5±18.9	13.6±16.2	0.311	16.3±17.4
HOOS, Sport/Recreation, after surgery, points	38.8±22.4*	48.9±20.2*	0.170	45.0±21.3*
HOOS, Hip Related Quality of Life, before surgery, points	25.9±16.1	25.6±15.4	0.936	25.7±15.4
HOOS, Hip Related Quality of Life, after surgery, points	58.5±26.0*	72.2±22.1*	0.089	66.8±24.3*

* Statistically significant differences compared with the corresponding indicators before treatment, $p<0.001$.

According to the questionnaire, the functional status of the patients, by Harris score for hip, significantly improved after surgery in both groups compared with the results before treatment. The intensity of the pain syndrome decreased, all indicators of the HOOS scale, including total, "Symptoms", "Pain", "Activities of Daily Living", "Sport/Recreation" and "Hip Related Quality of Life" also improved significantly ($p<0.001$). It was found that patients older than 45 years rated higher the intensity of the pain they experienced in the operated hip before surgery than younger patients (6.8±0.9 versus 5.9±1.2, respectively; $p = 0.036$). Statistically significant differences between the two groups after surgery were found only in the HOOS section "Pain". In the PPO group the result was better ($p = 0.035$). This was probably due to a higher percentage of complications in the STSO group. It was also shown that higher values of the HOOS section "Sport/Recreation" were obtained in younger patients compared with patients older than 45 years (52.0±21.4 versus 39.4±20.1; $p = 0.036$).

On the whole, the postoperative complications were found in 10 (27.8%) cases out of 36. The complications in the group STSO occurred 2.4 times more frequent than in the PPO group (6 cases (42.9%) out of 14 versus 4 cases (18.2%) out of 22 respectively. It should also be noted that in 2 cases out of 10 there was a combination of several complications, namely proximal femur intraoperative fracture and early dislocation, proximal femur intraoperative fracture and sciatic nerve neuropathy. Of 10 cases, revision HA was required in 4, of which in 3 cases the femoral component of the endoprosthesis was preserved (Table 3).

According to X-ray data, the consolidation of osteotomazed bone fragments was achieved on average in 7 months. (from 6 to 9 months). The nonunion of the femur osteotomized fragments or their fibrous fixation after HA was recorded as a whole in 6 (16.7%) cases out of 36, in 2 (14.3%) cases after STSO, and in 4 (18.2%) cases after PPO. The nonunion of the greater trochanter or femur osteotomy fragments was observed exclusively in the PPO group (4 cases of nonunion in 4). In one of these patients, the greater trochanter nonunion developed due to retaining structure failure. According to the X-ray, performed in 2 weeks after the surgery during the patient rehabilitation, the fixing cable shifted down along the femur. This led to the migration of the greater trochanter. However, in all cases with fibrous fixation or nonunion, these events were either not accompanied by pain and any clinical manifestations, or were associated with other more serious complications. Therefore, there were no surgery required to exclusively refix the femur osteotomized fragments. According to the X-ray, in 2 (9.1%) patients from PPO group there was a major trochanteric lysis, not clinically disturbing the patients. Also, in 2 (9.1%) other patients from this group, along with nonunion, the greater trochanter migration was revealed. The malposition of the endoprosthesis components was observed in 4 (18.2%) patients in the PPO group only.

Table 3

Complications and the rate of revision HA in groups with STSO and PPO in patients with total HA

Indicators	STSO group	PPO group	*p*	Total
Tonal HA, *n* (%)	14 (38.9)	22 (61.1)	—	36 (100)
Complications, total	6 (42.9)	4 (18.2)	0.140	10 (27.8)
Dislocations, *n* (%)	1 (7.1), in 10 days	3 (13.6), in 11 days; in 1 month.; in 2 months	1.000	4 (11.1)
Sciatic nerve neuropathy, *n* (%)	2 (14.3), immediately after the surgery	0	0.144	2 (5.6)
Aseptic loosening of the acetabular component, *n* (%)	1 (7.1), in 11 months	1 (4.5), in 4 years and 11 months	1.000	2 (5.6)
Intraoperative fracture of the proximal femur, *n* (%)	3 (21.4%), 2 of them were combined with other complications	0	0.051	3 (8.3%), 2 of them were combined with other complications
Infection, *n* (%)	1 (7.1), in 3 months	0	0.389	1 (2.8)
Revisions, Total	2 (14.3)	2 (9.1)	0.634	4 (11.1)
Due to loosening of the acetabular component, *n* (%)	1 (7.1)	1 (4.5)	1.000	2 (5.6)
Due to recurrent dislocation, *n* (%)	0	1 (4.5%)	1.000	1 (2.8%)
Due to prosthetic joint infection, *n* (%)	1 (7.1%)	0	0.389	1 (2.8%)

Discussion

The preoperative planning and careful selection of surgical techniques, which can prevent complications or reduce the risk of HA in the patients with Crowe III and IV HD, are of particular importance [19, 20, 21, 22, 23, 24]. In the preoperative planning, it is necessary to determine the difference in the length of the limbs. The special attention should be given to the cases with unilateral dislocation or with a history of surgery. In a unilateral dislocation, there is a difference in the degree of load distribution between the limbs and in the intensity of their growth. Over time, this can lead to a significant imbalance between the lower extremities with a difference in the length of the contralateral femur and tibia. This difference can only be determined by the X-rays [8]. We believe that in order to avoid errors during the planning the limb length correction and determining the size of the osteotomized fragment of the femur, in addition to the pelvis overview X-ray, it is necessary to use lower extremities X-ray, since the real difference in the length of the limbs very often turns out to be less than measured only by the pelvis survey X-ray only. In addition, the computed tomography is recommended by some authors in order to determine the shape and size of the femoral canal needed in selecting the femoral component [23]. When choosing a stem, some authors prefer modular components due to the fact that their use provides primary stability without additional fixation, and the 360 degree rotating proximal part eliminates excessive anteversion [12]. Others prefer to use wedge-shaped legs of rectangular cross section [13]. In our study, in most cases (more than 70%) the conical legs of the Wagner type were placed.

To date, there is no single strategy for HA in severe HD. Some authors report the successful use of a monolateral external fixation device before the primary HA in severe HD [25], while others report the benefits of shortening osteotomies [26]. There are works which demonstrate the positive results of arthroplasty in patients with high hip dislocation without shortening osteotomy and cranial displacement of the rotation center [27]. In our opinion, the restoration of the true center of hip rotation is extremely important, therefore, in such cases, we are inclined to choose the shortening hip osteotomy. Despite the difficulty of such an approach, there is a lot of clinical evidence of the efficacy of PPO and STSO [7, 19, 20, 23, 28].

Grappiolo et al. describe the results of 102 surgeries using STSO with an average follow-up of 11.3 years [3]. The average Harris score after surgery was 90.3 points. This is an excellent result. There were 4 early postoperative dislocations, and only in one case the open reduction was required. In one case, an intraoperative fracture of the greater trochanter was recorded. The osteotomized zone nonunion occurred in 4 cases. During the period observed by the authors, 5 revision surgeries were performed to replace the acetabular component and 2 surgeries to replace the femoral. The survival rate of the femoral components over a 10-year period was 97.8%. The survival rate of the cup and the stem was 95.9% at 10 years of follow-up. Effective results of STSO were also reported by Greber et al. Their rate of survival over 14 years was 75% [22].

The results of 136 HA performed with STSO in the HD patients with high hip dislocation were presented in the work of Tikhilov et al. [9]. The average follow-up was 26.3 months. Among intraoperative complications, the proximal femur fractures prevailed (14). In 2 patients, before their discharge from the hospital, a displacement of the greater trochanter occurred. The problem required the refixation. In 1 female patient, the acetabular component was placed below the acetabulum. It was replaced to the correct anatomical position. The following late complications were observed: delayed consolidation

in 12 cases, the greater trochanter pseudarthrosis (mainly due to the fixing screws fracture) in 13 patients, hip dislocation in 2 patients, acetabular component instability also in 2 patients, and stem instability and fracture in 1 patient [9].

The effectiveness of arthroplasty with shortening osteotomy for severe HD is lower compared with standard arthroplasty, and the incidence of early and late complications is high [6, 8]. Due to the high complexity of the surgery for severe HD, the surgery length and intraoperative blood loss increased, compared with the total HA in the standard conditions. Subsequently, this may affect the duration of the patient's rehabilitation [29]. After STSO, some complications, such as nonunion of bone fragments in the osteotomy zone and the periprosthetic fractures are possible [11]. There are the following risks of PPO: the sciatic nerve damage, perforation and fractures of the walls of the femoral canal, the greater trochanter nonunion [8, 29]. The results of the presented study were consistent with the above mentioned data. Although, there were a number of features which were characteristic just for this study. The complication rate was 27.8%, which is much higher than in the standard HA. However, it corresponded to the adverse events rate in arthroplasty with shortening osteotomies, which averaged 24.4±2.0%. Although, in STSO the adverse events rate could reach 41% [12]. According to our results in STSO, some complications developed in almost every second patient, while in PPO — only in every fifth. In turn, after PPO, the osteotomized bone fragments nonunion was more common. The results of our study demonstrated that the use of the PPO modification, consisted in refusal to employ the cortical screws for fixing osteotomized fragments of the greater trochanter, could be associated with the greater trochanter nonunion. In this case, the use only the cerclage fixation of the greater trochanter was not always sufficient.

According to our research, incomplete consolidation of bone fragments and the formation of a non-union in the zone of the femur shortening osteotomy developed in 16.7% of cases. This exceeded the rate of such complications according to the literature [9, 13]. Sciatic nerve neuropathy occurred exclusively in STSO group. We did not observe any periprosthetic fractures. In order to avoid one of the risks of PPO, a split of the narrow medullary canal walls during the femoral component placement, Mashkov et al. modified one of the surgery stages [23]. They recommend 3 longitudinal cuts on the outer lateral wall of the femur in the projection of the external lateral access to the hip. A number of authors used cables, cerclage sutures and plates to prevent intraoperative hip fracture, reduce the risk of instability and nonunion at the site of osteotomy [9, 19, 23, 28]. We used wire and / or cerclage seams in more than half of cases.

Many authors emphasized the importance of the surgeon's experience in STSO or PPO surgery. The surgeon's skills directly affect the effectiveness of the operation [9, 10, 19, 23]. An increased likelihood complications is associated with insufficient experience of the surgeon ("learning curve") [23]. To reduce the risk of complications, which, unfortunately, are inherent in each of the considered methods, additional fixation techniques are used, individual stages of the operation are improved. Probably, a rather high rate of complications, demonstrated in this paper, is also associated with the rarity of performing of this type surgery in our institution and the "learning curve".

The recommended instantaneous maximum lengthening of the limb in the total HA is 3 to 4 cm [8, 11]. It is believed, that when these figures are exceeded, the risk of neurological and vascular disorders increases [20]. However, Ozan et al. gave the opinion that there was no correlation between elongation of the limb and neuropathy [19]. In their opinion, the cause of this compli-

cation was the nerve contusion due to the aggressive surgical technique. The authors presented the results of 32 HA with STSO. The average limb lengthening was 3.2 cm without postoperative nerve dysfunction [19]. In our study, the average limb lengthening after surgery was 3 cm, sciatic nerve neuropathy developed in 5.6% of the cases, exclusively in the STSO group.

Most patients who are recommended HA for Crowe IV HD with high hip dislocation are young [21, 22, 26, 30]. In this regard, the restoration of muscle balance is of particular importance. This allows to maximize the postoperative results of treatment [26]. Besides, the patient's age affects the effectiveness of arthroplasty. The optimal age for total HA for Crowe IV HD is about 40 years. The earlier operation can result in the high probability of premature revision due to friction pair wearing [9]. In our practice, patients younger than 20 years were present. In order to maximally delay the need to replace the implant, the patients were undergone the ceramic-ceramic friction pair placement. This type of pair were known by its special strength and low wear [22]. According to 14-year follow-up, in the patients underwent HA with this pair of friction, the survival of the cup was observed in 97.9%, stem — in 95.8%, and the entire implant — in 95.7% of cases [31]. As for elderly patients, in this case it is difficult to achieve the expected functional increase after surgery due to decompensation of the adaptive capabilities of the lumbosacral spine and the knee. Age over 60 years is a critical factor for performing HA for HD with hip dislocation [9].

Both the STSO and PPO for total HA in patients with Crow III and IV HD have good reconstructive capabilities and sufficient efficiency. The high rate of postoperative complications (27.8%), can be explained by the severe degree of HD. The latter made the HA difficult to perform in this group of patients, as well as difficult to perform the shortened osteotomies. Although the percentage of postoperative complications in study was high, revision intervention was required only in 11.1% of cases, and the survival rate of the femoral component was 97.2%.

A certain limitation of our work was a small number of observations, which is generally characteristic of studies of the results of shortening hip osteotomy due to the small number of such patients. Accordingly, we were unable to identify the clear advantages of any of the described options for shortening osteotomy. In our practice, we give preference to STSO, since, in our opinion, it eliminates the possibility of migration of the greater trochanter and, if properly performed, does not require the use of additional metal structures for the greater trochanter fixation. However, this question may finally be resolved only in subsequent studies, preferably with a prospective design and, possibly, with a randomized choice for shortening osteotomy technique.

Publication ethics

Patients gave voluntary informed consent to participate in the research study.

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Authors' contribution

A.A. Korytkin — research concept and design, literature review, research conduction, data analysis and interpretation, data statistical processing, editing

S.A. Gerasimov — research conduction, editing

Ya.S. — investigators coordination, literature review, research conduction, data analysis and interpretation, data statistical processing, text preparation

K.A. Kovaldov — research conduction, text preparation

E.A. Morozova — collection of material and database creation, literature review, research conduction, text preparation

S.B. Korolev — research design, editing

Yo.M. El mudni — research conduction, text preparation

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