УДК 616.728.2-089.844-089.193.4:616.718.16 DOI: 10.21823/2311-2905-2019-25-1-122-141

Classifications of Acetabular Defects: Do They Provide an Objective Evidence for Complexity of Revision Hip Joint Arthroplasty? (Critical Literature Review and Own Cases)

R.M. Tikhilov [1,2], I.I. Shubnyakov [1], A.O. Denisov [1]

[1] *Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russian Federation*

[2] *Mechnikov North-Western State Medical University, St. Petersburg, Russian Federation*

Abstract

The present paper bears discussion in nature and doesn't claim for any scientific evidence. ***The purpose*** is to identify which classification of acetabular defects currently is the most employed in revision hip joint arthroplasty, and how precise this classification reflects the true defect severity and gives the objective grounds for selection of revision implants. ***Materials and Methods.*** The authors conducted literature analysis in PubMed and eLIBRARY for the last five years. 170 publications in English, German and Spanish languages as well as 15 works in Russian language dedicated to classification of acetabular defects were selected. ***Results.*** W. Paprosky classification was found to be the most applicable, namely, in 65,9% of foreign publications and in 100% of Russian papers. AAOS classification was used in 22.9% of cases, Gross and Saleh — in 4.1%, Gustilo and Pasternak — in 1.2%. 5.9% publications reported use of two classifications. The reasons for Paprosky classification popularity is the possibility to evaluate defect basing on standard pelvis X-rays in preoperative stage as well as in retrospective research. At the same time, according to literature, the confidence of Paprosky classification (accuracy of correspondence to intraoperative findings) varies from 16 to 66% for different areas of acetabulum, and during reliability assessment (consistency between different specialists) kappa coefficient varies from 0.14 to 0.75 depending on experience of the specialist and specifics of the defect. One of the possible reason for discrepancies in assessment of defect grade are the iatrogenic and posttraumatic changes of the acetabulum. Nevertheless, Paprosky classification is evolving and, considering additional parameters, like type of defect (contained or non-contained) and pelvic ring continuity, it allows to create a full-fledge algorithm for selection of revision implants and defect replacement which is adequate to the up-to-date surgical needs. At the same time onrush of digital technologies of 3D-visualization considerably expands our possibilities for preoperative defects assessment and offers promising potential for development of new classifications, whose benefits are yet to be evaluated.

Keywords: revision hip joint arthroplasty, classification of bone defects, Paprosky classification.

Cite as: Tikhilov R.M., Shubnyakov I.I., Denisov A.O. [Classifications of Acetabular Defects: Do They Provide an Objective Evidence for Complexity of Revision Hip Joint Arthroplasty? (Critical Literature Review and Own Cases)]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2019;25(1):122-141. (In Russ.). DOI: 10.21823/2311-2905-2019-25-1-122-141.

Igor I. Shubnyakov; e-mail: shubnyakov@mail.ru

Number of revision hip replacements (HR) is increasing every year around the world [1–4]. In some countries with minor annual increase of overall number of arthroplasties the rate of revisions substantially outpaces the growth rate of primary procedures [3, 5]. In other countries where primary hip arthroplasty is still intensively develops revision rate growth is substantially lower, but non the less overall number of such procedures is increasing every year [4, 6]. Revision procedures demand significantly more solid resources — availability of specialists skilled in revision techniques, heavy stock of various implants, corresponding instruments, bone grafting capacities which ultimately significantly increases economic expenditures of separate institutions and country in general [5, 7–9]. At the same time the outcomes of revision surgeries are far from desired — the complications rate is much greater than after primary procedures [10, 11, 12, 13] and five-year implants survivorship after different revisions varies from 67,0 to 84,8% [14]. Despite changing structure of indications for revisions and increased importance of recurrent dislocations and infection [3, 15] many national arthroplasty registers demonstrate that for many years aseptic loosening and peri-implant osteolysis remain the key factors resulting in bone defects of various span and site [16].

Preoperative planning of revision stipulates that surgeon exactly understands all features of bone defect to work out the optimal treatment option, select necessary implants and defect replacement technique, and, probably, specialized instruments or decide for production of custom made implants [17–21].

Various classifications were developed for evaluation of periacetabular bone loss in revision joint arthroplasty. The key aim of such classifications is the description of defects specifics to unify treatment solutions as well as a possibility for comparison of various procedures efficiency in similar situations. Some classifications have defect type and volume of bone loss in the basis (Gross [22], Parry [23]), the other — anatomical landmarks ensuring more precise preoperative planning (Paprosky [24], AAOS [25], Gross in modification of Saleh [26].

The aim of the to study — answer the following questions in the present publication: 1) which classification of acetabular defects is the most used today? 2) how precisely this classification reflects the true severity of defect and objectifies the choice of revision components? 3) are classifications needed today in the context of available complete defect visualization based on current CT examination with 3D modeling of the image?

According to some authors Paprosky and AAOS classifications are the most cited currently in literature [27–30]. Other authors consider Saleh and Gross classification as the most used [30–33].

For the present study the authors performed literature search for the past five years in PubMed database on keywords „acetabular revision“ and „acetabular defect classifications“. Only full text papers are the subject of analysis. 170 out of 956 publications contained the information on application of classifications for acetabular defects. 112 (65,9%) papers mentioned Paprosky classification, authors of 39 (22,9%) used AAOS system, 7 (4,1%) papers reflected application of Gross classification in modification of Saleh, two (1,2%) papers — Gustilo and Pasternak [34], and 10 (5,9%) publications considered two classifications.

The authors also searched Russian electronic scientific library — eLIBRARY. 15 publications were found by request for „acetabular revision“ and „acetabular defect classification“ which contained information on defects classification in revision replacement. Paprosky classification was used in 14 papers, abstract of one publication contained indication for AAOS classification and paper text — Paprosky classification.

Thus, we can conclude that W. Paprosky classification published in 1994 is used in the absolute majority of cases recently to standardize the defects. This classification has clear anatomical landmarks which according to many authors enable high reproducibility and ensured the highest popularity among surgeons [23]. The creator himself in one of his publications „modestly„ notes that Paprosky classification is most often used to identify location and volume of acetabular bone loss [35].

At the same time the American Academy of Orthopaedics Surgeons (AAOS) classification system [25, 32] is the most detailed from the above mentioned, it allows to rather precisely localize the defect and visualize it's pattern (segmental, cavitary, combined) (Table 1). However, this classification doesn't reflect the severity of such alterations: not necessarily the defect of type III is more severe than type II, and moderate defect of type II is significantly easier for revision as compared to extensive defect of type I. Accordingly, the present classification only insignificantly determines the defect replacement tactics and technique of reimplantation of acetabular component [36] which complicates assessment of outcomes after various surgical solutions in cases similar in respect of severity.

In contrast to AAOS classification rating second on citation rate the classification of the German Society for Orthopaedics and Traumatology (DGOT) published in 1997 [37] (Table 2) is mentioned only once for past five years in the work of K. Horas et al [31]. This classification has much in common with AAOS but the volume of defect is also poorly specified. Although description contains clarifications, their clinical application is difficult and almost impossible in preoperative period. In particular, defect types II-IV are described as mono-segmental. Type is identified after corresponding localization of the leading defects. All defect types, besides, can have simple cavities and bone defects <50% of other acetabulum segments. So, the final assessment under this classification is possible only during the surgery after removal of acetabular component. The present evaluation system is constructed more logically in respect of severity but is rather subjective due to no indication of the volume of the main defect. Besides, in contrast to AAOS the present classification is much less recognized in English language literature.

Table 1

AAOS classification of acetabular bone defects [25]

Type	Name	Description
Type I	Segmental	Loss of part of the acetabular rim or medial wall
	Peripheral: Superior Anterior Posterior	
	Central (no medial wall)	
Type II	Cavitary	Volumetric loss in the bony substance of the acetabular cavity
	Peripheral: Superior Anterior Posterior	
	Central (medial wall preserved)	
Type III	Combined	Combination of segmental bone loss and cavitary deficiency
Type IV	Pelvic discontinuity	Complete separation between the superior and inferior acetabulum
Тип V	Arthrodesis	Arthrodesis

Table 2

Classification of the German Society for Orthopaedics and Traumatology (DGOT[1]) [37]

Type	Name	Description
Type I	Simple cavity	After removal of loosened acetabular component the ring of acetabulum component is preserved, roof and rims of acetabulum are intact
Type II	Mono-segmental defect	Segmental defect of medial wall, usually developed in result of central protrusion of the implant. Perforation of acetabular floor and, consequently its significant weakening is observed. Remaining part of ring is not damaged
Type III	Mono-segmental defect of the roof	Segmental defect of superior acetabular rim in the area of the main load. Originates after cranial migration of loosened cup. Bone structures of the remaining acetabular ring are almost not affected
Type IV	Mono-segmental defect of anterior or posterior rim of acetabulum	This segmental defect is located either on anterior, or on posterior rim of acetabulum. Rarely seen as isolated defect. Nevertheless, should be indicated for reason of systematization. Such defect is mainly seen in posttraumatic arthrosis or in dysplasia
Тип V	Bi-segment superior-central defect	Rather common type of defect on superior rim and floor of acetabulum arising after craniocentral migration of loosened cup
Тип VI	Three segment defect (roof, floor and rim)	Defect of anterior or posterior rim is observed in addition to combined defect of type V
Тип VII	Pelvic instability	No bone contact between superior and inferior parts of acetabulum. These segments can move relative to each other, full acetabular instability is observed. Defects on anterior and posterior walls

* DGOT — Deutschen Gesell schaft für Orthopädie und Traumatologie.

Other systems like Gross (Saleh), Gustilo and Pasternak, as well as Paprosky are referring exactly to severity degree which makes them more user-friendly. Gross classification with supplements by Saleh is based on the volume of preserved acetabulum and defect pattern — contained or uncontained (similar to cavitary and segmental defects to some extent) which is not always possible to evaluate on X-rays, consequently requires precise intraoperative control, and is hardly complex to do in retrospective X-rays analysis (Table 3). However, the present classification provides quite clear algorithm for surgical decision making during the procedure [32].

Bone loss severity index according to Gustilo and Pasternak [34] was used three times for past five years (twice as the only assessment tool and once in combination with Paprosky classification) (Table 4). This tool looks rather primitive in contrast to other classifications with insufficient specification of visualized changes, broad interpretation of X-ray signs and rather wide choice of surgical options for any category.

In turn, Paprosky classification is based on the analysis of standard X-rays and by description allows to considerably foresee potential surgical challenges during revision and to a certain extent can serve as an algorithm for revision THR, all of the above is making this classification the most interesting for clinical application. Reference to four simple X-ray signs a surgeon can classify any status basing on standard AP pelvis view (Table 5). Uninterrupted Kohler line features integrity of medial wall and anterior column, while any overlapping of acetabulum component with this line witnesses damage of those structures. Distinct teardrop also confirms intact medial wall as well as inferior aspects of anterior and posterior columns. Sciatic osteolysis implies injury of posterior wall and posterior column, while vertical migration of acetabular component — injury of acetabular dome [36]. However, identification and interpretation of those signs bear certain subjectivity leading to discrepancies in evaluation of bone loss severity by various specialists [23, 38].

Any classification is evaluated by accuracy of reproducibility, in our case, to what extent of uniformity various experts evaluate the same X-rays. Another criteria is reliability (validity) — to what extent the X-ray evaluation of defect corresponds to intraoperative findings. Cohen's kappa (κ) is used for evaluation of both criteria, where zero value demonstrates a very weak probability of facts correlation, and value close to 1 features almost complete match of two opinions or facts.

Table 3

Classification of acetabular bone loss by A. Gross amended by K. Saleh [22, 26] and suggested clinical options [32]

Type	Description	Reconstruction options
I	No significant loss of bone stock	Uncemented or cemented hemispherical acetabulum component
II	Contained loss of bone stock (cavitary expansion of acetabulum without deficit of the acetabular walls)	Uncemented hemispherical acetabulum component or impaction bone grafting
III	Uncontained loss of bone stock involving segmental defect less than 50% of acetabulum (minor column defect, a — anterior, or b — posterior column)	Uncemented hemispherical acetabulum component and small structural graft or metal augment
IV	Uncontained loss of bone stock involving segmental defect more than 50% of acetabulum with anterior and posterior column defect. (In case of >50% acetabulum bone loss involving mainly medial wall but with intact columns, such defect is classified as type II due to availability of columns for reconstruction)	Large structural graft protected by reconstructive cage or metal augment also protected by cage
V	Pelvic discontinuity with uncontained loss of bone stock	Cup-cage system with large structural graft or metal augments

Table 4

Classification of acetabular bone loss by Gustilo and Pasternak [34]

Type	Description
I	Radiolucent lines around the acetabular component, minimal bone loss
II	Severe acetabulum enlargement. Marked thinning of acetabulum
III	Anterior, superior and/or central bone loss causing instability of the implant
IV	Acetabular collapse with fracture or severe bone loss

Table 5

Classification of acetabular bone loss by Paprosky [24] with refinements [39, 40]

Type	X-ray findings				Description
	Migration of rotation center of femoral component	Ischial lysis	„Teardrop„	Kohler's line	
I	Minimal or absent	No	Intact	Intact	Acetabular rim and both columns are intact, there are minor contained defects; >90% bone contact
IIa	Minor	Minor (<7 mm)	Intact	Intact	Minor superior defect, 80–90% bone contact
IIb	Moderate (<3 cm)	Minor (<7 mm)	Moderate lysis	Intact	Supero-lateral displacement — not exceeding 3cm, >60% bone contact
IIc	Medial (< 2 cm)	Minor (<7 mm)	Moderate lysis (loss of lateral contour) up to severe lysis (loss of medial contour)	Moderate disruption	Isolated medial migration, intact rim, broken Kohler's line
IIIa	Major cranio-lateral (>3 cm)	Moderate (7–14 mm)	Moderate lysis (loss of lateral contour)	No disruption	Major superior displacement, rim is affected no more than for 1/2 of its diameter, teardrop is poorly visualized, minimal ischial osteolysis, <60% bone contact
IIIb	Severe cranio-medial (>3 cm)	Severe (≥15 mm)	Severe lysis (loss of medial contour)	Major disruption	Severe defect, only remnants of columns are preserved, bone contact less than 40%

There were many attempts to verify accuracy and reliability of Paprosky classification. Back in 1996 Joerg Jerosch et al presented an interesting study: 350 X-rays were evaluated by six surgeons with different professional experience. Acetabular rim defect was evaluated correctly only in 66% of cases, interpretation of bone loss signs demonstrated even poorer results — medial defects were adequately assessed only in 49% of cases. In general, accuracy of preoperative defect verification was 25%, the values were improving with more skilled surgeons and decreasing with more severe acetabular defects up to 16%, the consistency between the experts was quite moderate (κ = 0,54) [41]. At the same time W. Paprosky et al in their original paper reported 100% match of preoperative defect evaluation with intraoperative findings for type I bone loss, 89% — for type II and 95% — for type III [24], other research groups were unable to achieve similar comparability [40, 42]. However, quantitative analysis of alterations by Raymond Yu et al allowed to significantly specify verbal grading of moderate, severe etc [40]. In their study a more substantial defect of „teardrop" was related to higher values of intraoperative defects (p = 0,0015), bigger disruption of Kohler's line was associated with a larger area of intraoperative defects (p = 0,0011), more complex superior X-ray defect was related to a greater area of bone loss in superior aspect of acetabulum during the surgery (p<0,0001). At the same time, no significant relation between ischial osteolysis degree and four grades in accordance with classification (p = 0,21), but severe intraoperative defects were assessed as marked on preoperative X-rays.

Data on Paprosky classification reliability is also contradictory — Cohen's kappa (κ)

varies from 0.14 up to 0.75, while most often the authors observed values ranging from 0.4 to 0.6 [18, 23, 40, 42]. The following reasons can account for such heterogeneity: subjectivity in classification evaluation, challenges during identification of anatomical landmarks on X-rays, challenges with interpretation of X-ray findings themselves. Other researchers note the importance of training in application of classification. After training and repeated X-ray analysis the Cohen's kappa increased from 0.66 to 0.71, whereas without training the Cohen's kappa coefficient increased only from 0.50 to 0.53 which was statistically insignificant [40]. In general the majority of authors agree that Paprosky classification is valid but bears substantial subjectivity and requires standard and objective protocol for registration of measurements [31, 42].

At the same time we should not forget that the present classification was developed for periacetabular bone loss resulting from osteolysis and loosening of acetabular component and almost doesn't consider specifics of iatrogenic and posttraumatic revision defects [38]. Besides, classification is based on pelvic X-rays examination in AP view, while during almost 25-year history of application of this classification new options were developed for creating solid virtual models based on CT scans which significantly expanded our vision and capabilities. Claus et al in their cadaveric study of 2003 demonstrated that accuracy of evaluation for perioprosthetic osteolysis on standard pelvis X-ray doesn't exceed 40% but can be increased up to 70% with additional views. In particular, minor periprosthetic defects of sciatic bone or acetabular rim were hardly identifiable basing on one X-ray, sensitivity approximated 15% [43]. Other *ex vivo* studies using hip joint pelvic models demonstrate similar results and causing doubts on reliability of separate X-ray for visualization of acetabular defects [44].

No doubt that many refinements made in subsequent papers allows to give more specifics to evaluation of separate signs and enhance accuracy of reproducibility. Additional parameters (segmental or cavitary patterns of defects) and assessment of pelvic continuity enables this classification to act as full-fledged algorithm for defects replacement and choice of implants in various clinical cases (Fig. 1) [45]. Non-the-less even the authors of this classification in their recent publications report the need for additional defect assessment with 3D-modeling techniques based on CT data to enhance visualization accuracy and to produce customized implants [46].

Disagreements between experts in our practice are not infrequent due to mismatch of common interpretation of X-ray findings and real complexity of revision procedure. Such disagreements most often occur during evaluation of iatrogenic and posttraumatic defect. This can be illustrated by a X-rays of a male patient, 28 years old, who underwent total hip replacement 2 years ago in another hospital due to consequences of acetabular fracture (Fig. 2). Cup displacement and consequently of rotation center upwards much over 2 cm, no osteolysis of sciatic bone, „teardrop„ is visualized through with some deformity, disruption of Kohler's line is unidentifiable due to displacement of the whole posterior column. The present defect can equally be classified as IIIa and IIIb while CT demonstrates that initially the cup was inserted with superior and posterior displacement and there was no defect of posterior wall. During surgery the cup bed was formed closely to the true rotation center with about 65% of contact with underlying bone. First the acetabular component was inserted and good fixation was obtained, but considering sufficient coverage deficit of postero-superior aspect (about 35%) a metal augment was inserted at the second stage providing fixation to the cup by bone cement. The present clinical case clearly demonstrates impossibility to evaluate the features of the defect and it's classification by roentgenological markers used in Paprosky classification.

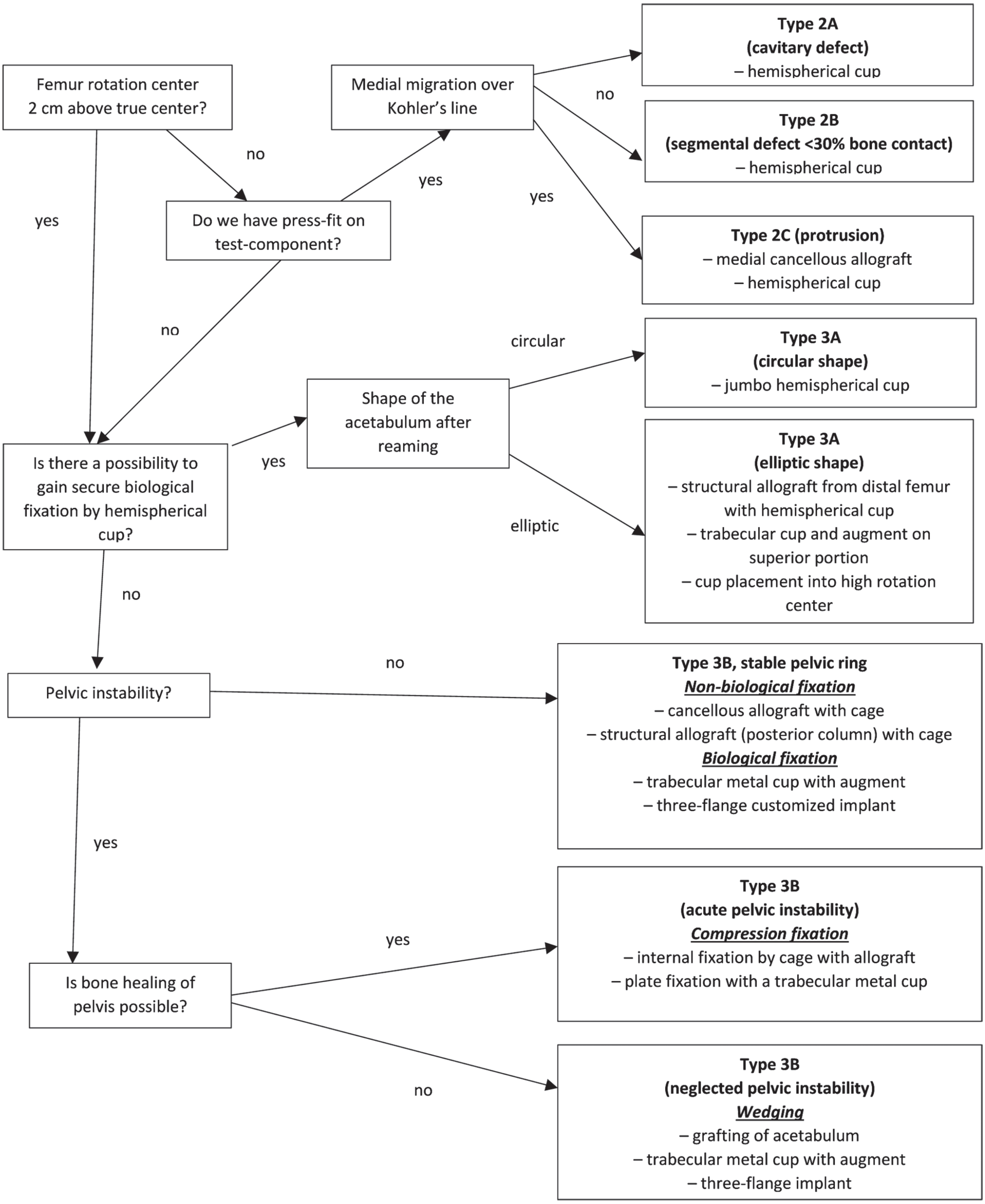
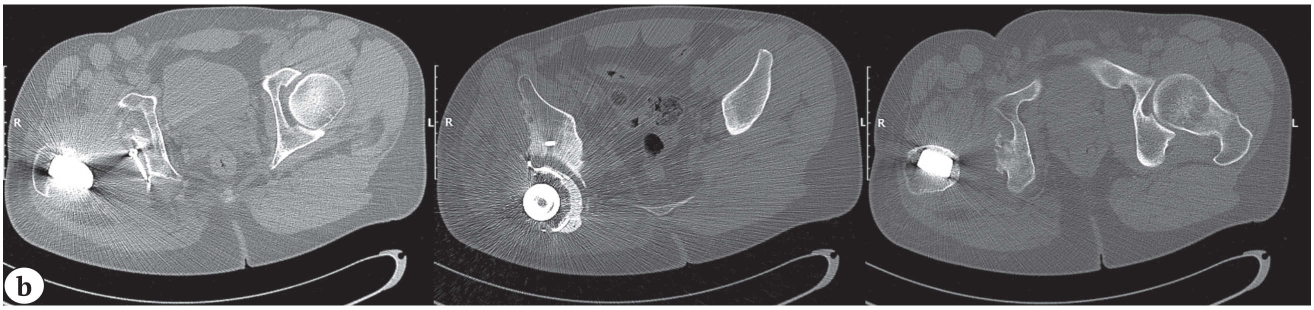
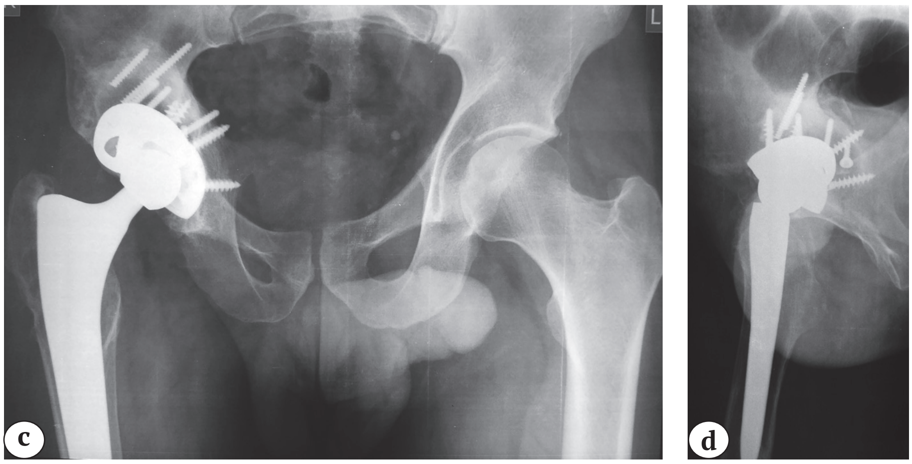


Fig. 1. Algorithm of treatment for acetabular defects (by the courtesy of W. Paprosky) [45]

Fig. 2. X-rays and CT scans of male patient, 28 y.o., with loosening of acetabular component and consequences
of acetabular fracture:
a, b — prior to revision;
c, d — two years after revision





Another case is iatrogenic defect when signs on standard pelvis X-rays do not reflect true severity of the defect. In particular formation of high rotation center in case of severe dysplasia is on the widespread arthroplasty methods [47, 48]. However loosening of highly positioned cup can be immediately considered as IIIa type defect despite the fact that in reality the inferior aspects of the acetabulum are intact and preserve the possibility of secure primary fixation and perspectives of further osteointegration. X-rays of female patient, 55 years old, demonstrate cranial cup displacement approximately of 7 cm after multiple surgeries where acetabular component was positioned into the false acetabulum. There was a defect of superior wall at time of revision with no lysis in internal and posterior walls. Formally such defect is classified as type IIIa while true anatomical changes do not correspond fully to this type — inferior structures of acetabulum remain minor affected and allow to form a good bed for uncemented cup (Fig. 3).

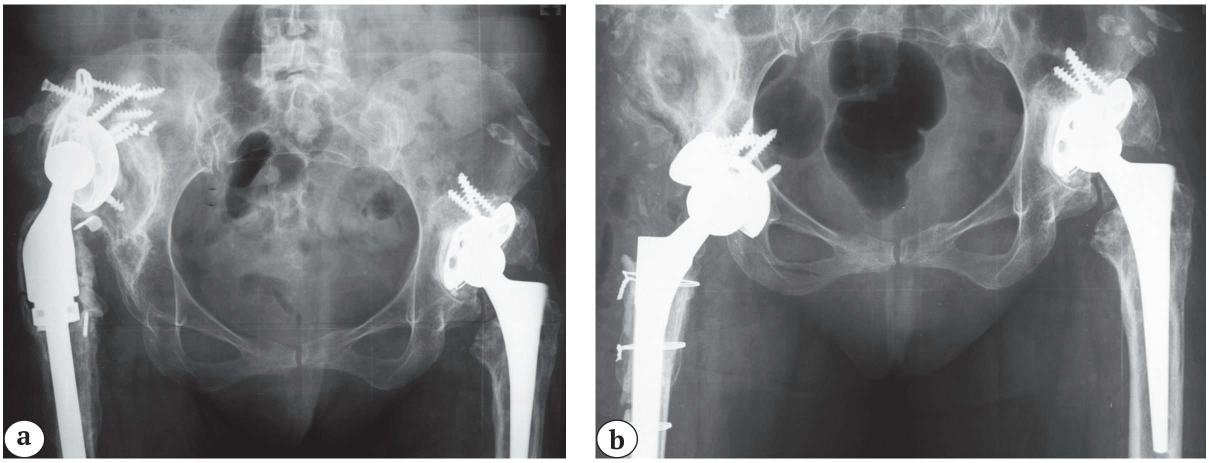


Fig. 3. X-rays of female patient, 55 y.o.: a — at admission; b — after revision

We can see also a reverse situation when at first sight insignificant defect in the acetabular floor (IIc type by Paprosky) is the masked severe defect of IIIb type. The present clinical case was courteously provided by out colleague from a different hospital.

Female patient of 47 years old with bilateral congenital dislocation was earlier operated on the left joint (shortening Paavilainen osteotomy) (Fig. 4). During surgery on the right joint using similar surgical technique a fracture of acetabular floor occurred, double grafting was performed and additional cup fixation by screws. Postoperative X-rays show medial migration less than 2 cm, minor vertical migration, alerting though is only the complete destruction of „teardrop" which is allowable for IIc type. Naturally, there is no ischial lysis. However, next day after surgery further cup migration occurred which significantly worsened the situation and required complex reconstruction by a titanium mesh with impaction allografting.

Another case of mismatch between apparent and true severity of the defect is pelvis X-ray of a male patient, 56 years old. In 13 years after primary hip replacement the patient was hospitalized for revision due to major wear of polyethylene insert and periprosthetic osteolysis (Fig. 5 a–c). Pelvis and hip joint X-rays in AP and lateral views demonstrated significant lysis in proximal femur and moderate retroacetabular osteolysis. No disruption of Kohler's line, minimal ischial lysis, no damage to internal contour of „teardrop", lateral contour is not visualized (probably due to overlap with cup or to osteolysis), medial displacement of rotation center only in range of insert weak. This defect can be classified as IIb and possibly IIa maximally by Paprosky. During surgery after removal of the insert the absence of medical wall under the cup was observed. Cup was removed, bone grafting with structural allograft from femoral head was performed and, considering preserved acetabular ring, an uncemented hemispherical revision cup was inserted (Fig. 5 d). 7 years postoperatively there is partial graft lysis, minor migration of the inferior cup border without clinical signs (Fig. 5 e).

In practice we face complications during X-rays assessment based on such criteria as contained and uncontained defect and judging on the volume of the defect. Such criteria are very important for unified evaluation of surgery outcomes and development of a single approach to surgical tactics. Perhaps further research dedicated to the more detailed specification and definition of criteria for describing above defects is needed. Criteria described in classification of Saleh and Gross could be a good supplement to the anatomically oriented Paprosky classification. Saleh and Gross criteria identify such notions as contained and uncontained defect subdividing the latter one depending on the bone loss volume (less or over 50%). Gross classification in general was intended for intraoperative defects evaluation and it's task was to justify use of various allografts.

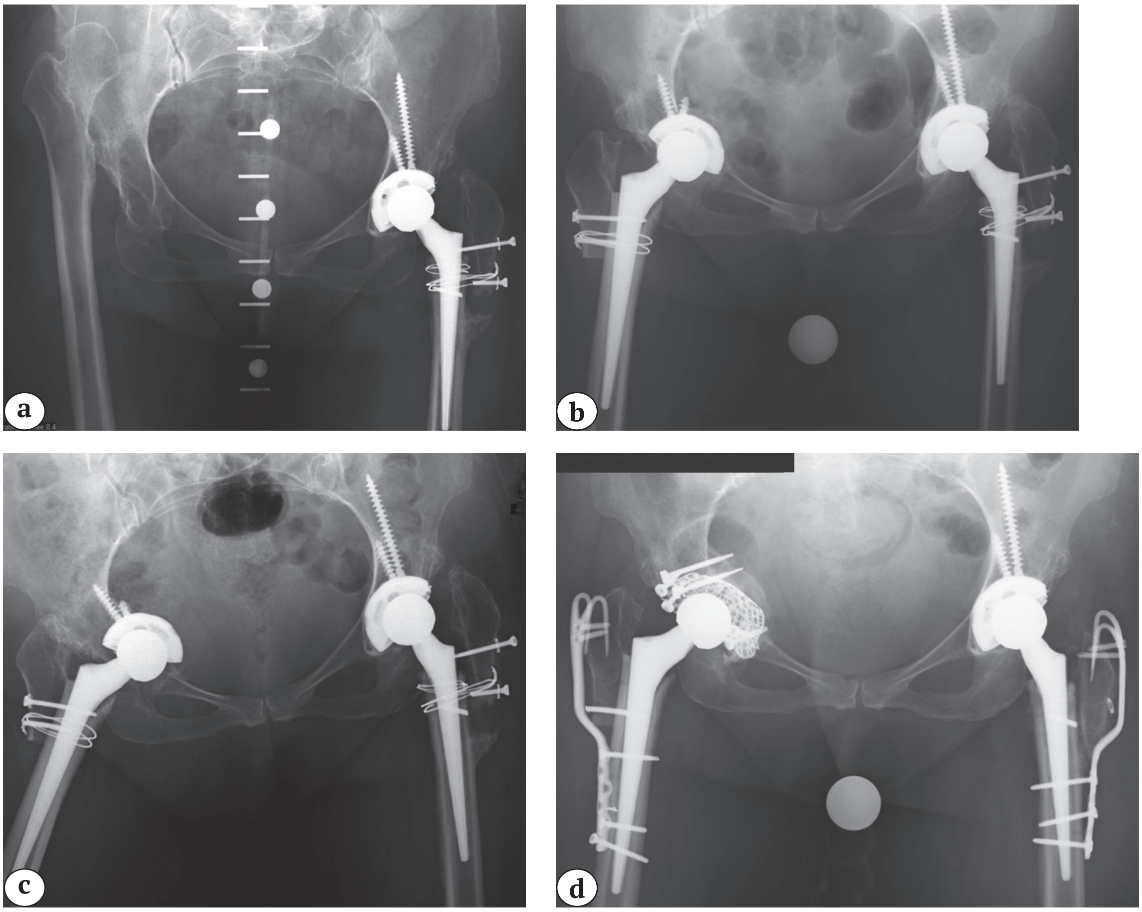


Fig. 4. X-rays of female patient, 47 y.o.:
a — prior to first surgery; b — immediately after first surgery;
c — one day after surgery; d — after revision surgery

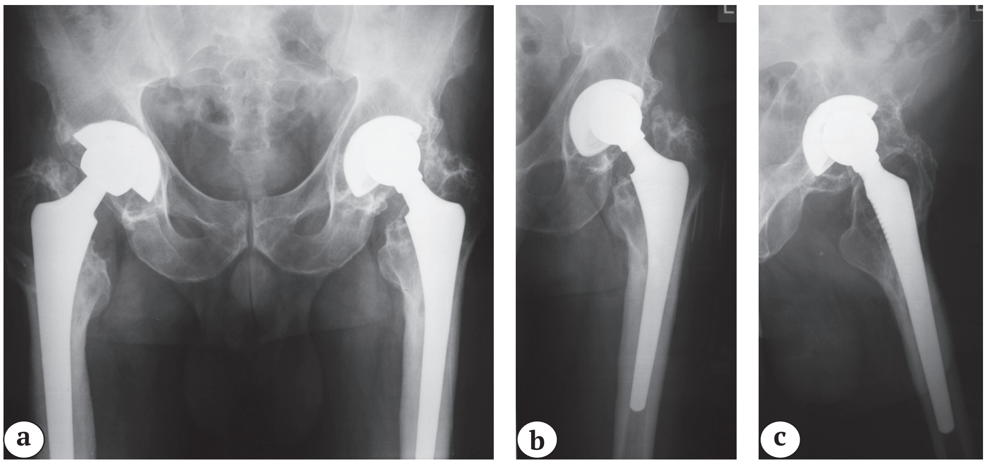


Fig. 5. X-rays of male patient, 56 y.o.:
a, b, c — 13 years after surgery

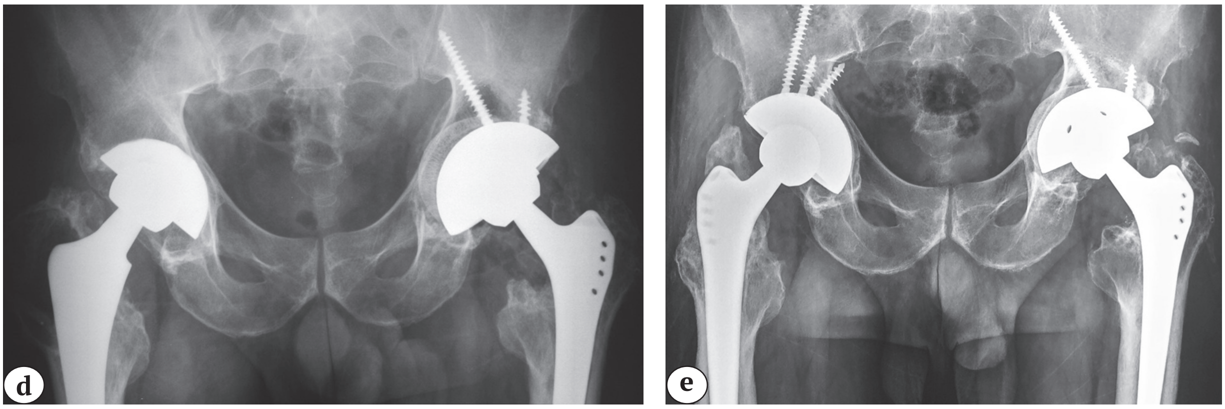


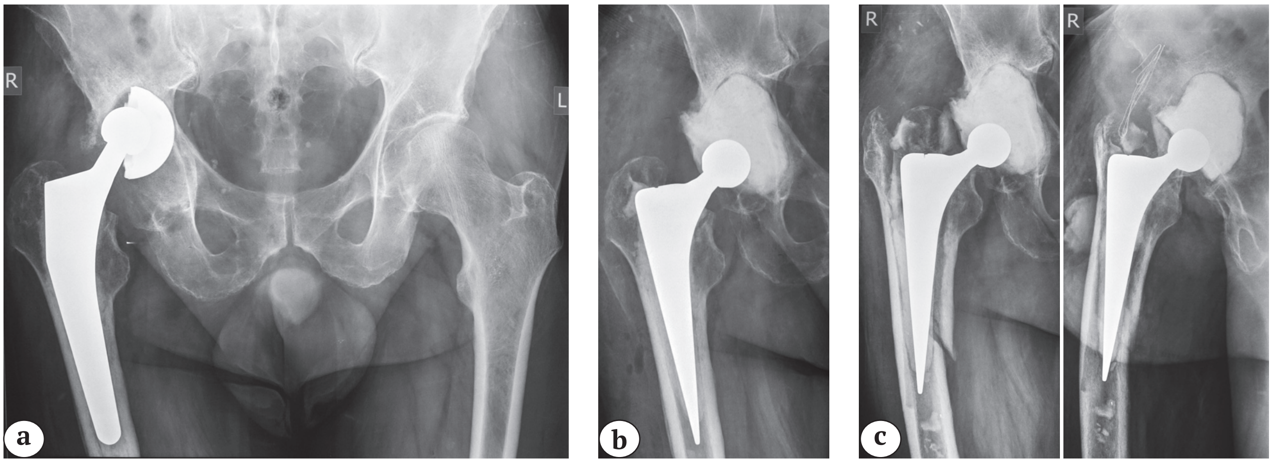
Fig. 5(d, e). X-rays of male patient, 56 y.o.: d — after revision; e — 7 years after revision surgery

Figure 6 presents X-rays of male patient, 65 years old, with loosening of the cup in 5 years after primary surgery, periprosthetic infection and acetabular defect of IIIs type. Two stage procedure was used. First included implantation of articulating spacer. 2 months postoperatively the patient fell and sustained periprosthetic fracture. Spacer was replaced by a prosthesis. Considering contained pattern of IIIa defect despite of its substantial size impaction bone grafting was performed and bone cement fixation of polyethylene cup — solid primary fixation obtained.

Even the more severe defects with significant medial cup migration but with preservation of medial support provided by displaced medial wall allow to use standard hemispherical cups for revision in combination with impaction bone grafting.

Female patient, 56 years old, twice operated, underwent latest surgery 5 years ago (Fig. 7). This is a IIIb type defect by the degree of superior-medial migration, however, the ischial lysis is insignificant (less than 7 mm). Medial „teardrop“ contour is preserved and the most important is that medial wall is preserved thought with major deformity. Preserved medial support (contained defect type) allowed to perform impaction bone allografting and insert a hemispherical uncemented cup additionally fixed by two screws. In 6 months and in 11 years we see gradual compaction and resorption of allograft, inferior cup migration is observed but without clinical signs of cup loosening. The patients thinks revision unnecessary.

On the contrary, an uncontained defect pattern, even with minor medial displacement, requires the use of reconstructive anti-protrusion cages. Female patient, 52 years old, primary hip arthroplasty performed one year before (Fig. 8). Pelvis X-ray demonstrated moderate disruption of Kohler's line (medial migration less than 2 cm) and minor cranial displacement (rotation center less than 3 cm from line connecting „teardrop“), medial „teardrop“ contour is preserved. Ischial lysis is difficult to evaluate but considering short period from previous surgery most likely the lysis will not be major. Formally this is a IIc type defect but with uncontained lesion of medial wall. Thus, our implant of choice was anti-protrusion Burch-Schneider ring.



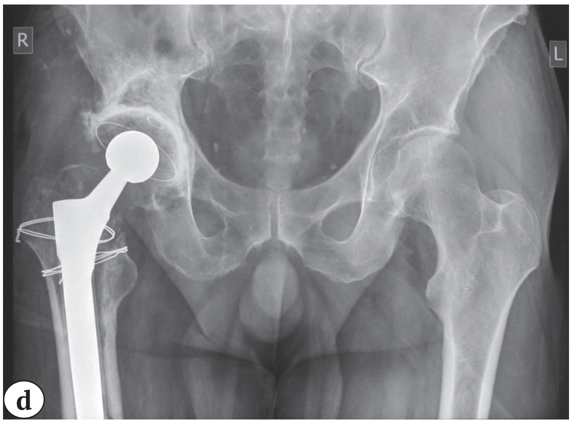
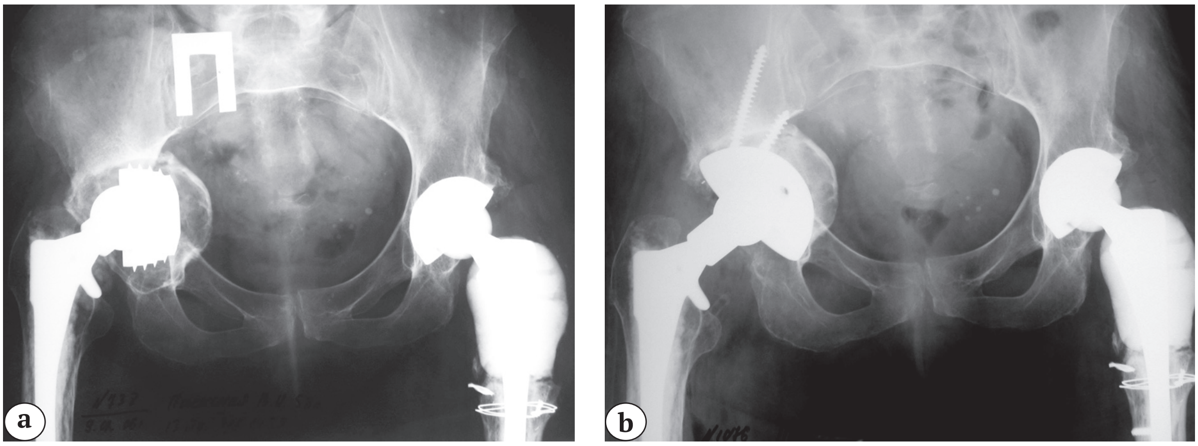


Fig. 6. X-rays of male patient, 65 y.o.:
a — 5 years after primary hip replacement;
b — after insertion of articulating spacer;
c — after fall;
d — after revision



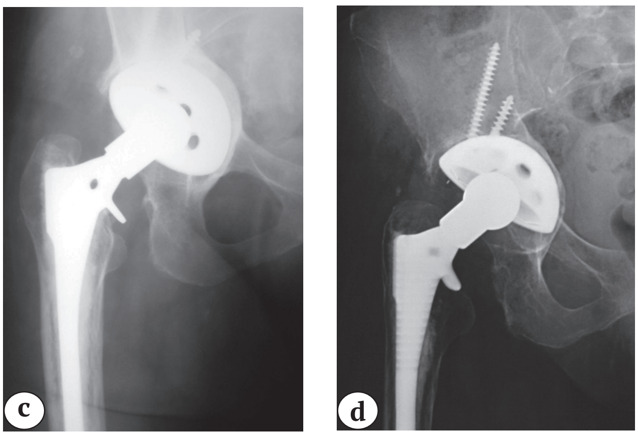


Fig. 7. X-rays of female patient, 58 y.o.:
a — prior to surgery;
b — immediately after the surgery;
c — 6 months after surgery;
d — 11 years after the surgery

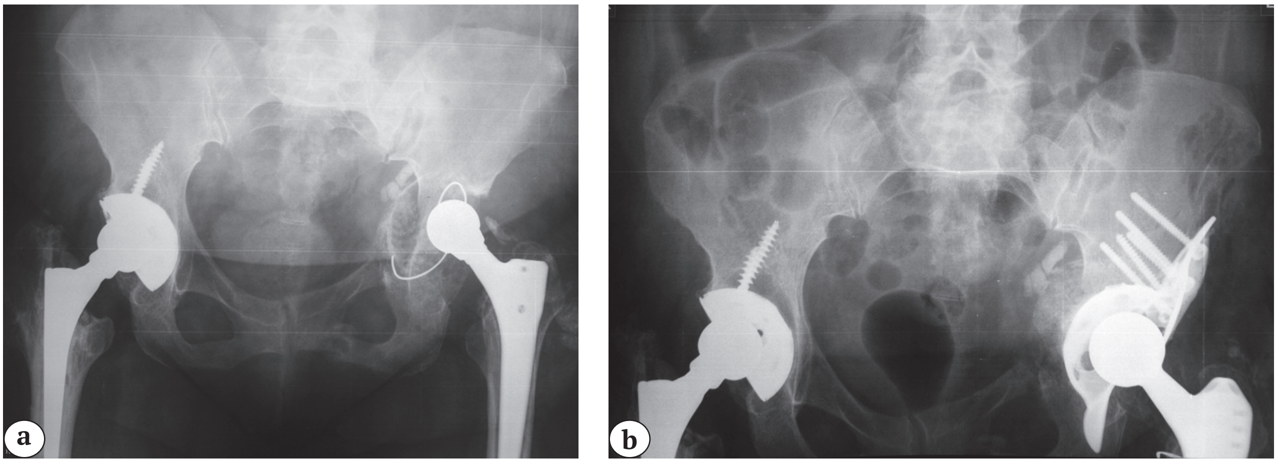


Fig. 8. X-rays of female patient, 52 y.o.: with IIc type of defect:
a — at admission; b — after revision

When discussing a defect of IIIa type we understand that we talk about so called „up-and-out" defect, which is the damage of superior-lateral aspect of acetabulum with minimal damage to anterior column and acetabular floor, meaning that most likely we will need to use special augments or implants providing support for the cup in the superior-lateral portion of acetabulum. However, IIIa type defects are highly heterogeneous group of patients and subdivision of defects for contained/uncontained or cavitary/segmental would make the used techniques more comparable. All patients in figure 9 have roentgenological signs distinctive for IIIa defect type, however, in case of contained or cavitary defects a standard high-porous cup will be sufficient (Fig. 9a). In more complex cases, with uncontained or segmental defect use of augments (Fig. 9b) or customized implants (Fig. 9 c) is a must.

When discussing IIIb type defects we understand that osteolysis area and destruction of acetabulum affected primarily superior, medial walls and anterior column with quite limited host bone stock. Very likely this is the most challenging acetabular defect from surgical standpoint, if we do not consider pelvic ring disruption. However, possibly clarification of such defect type in terms of volume of bone loss and support ability of the medial wall would, undoubtedly, make the picture more detailed. All patients in figure 10 had „up-and-in" damage but various surgical techniques were applied due to various volume of defects. Can we equate those defects? Can we foresee accuracy and predict late outcomes? Apparently, no.

Paprosky classification was suggested about 25 years ago and for all those years served as an algorithm for surgical decision making basing on the analysis of anatomical changes on overall pelvis X-ray. Meanwhile computer tomography with the possibility of 3D reconstruction became an integral part of the clinical practice which, on the one hand, significantly expanded our visualization of acetabulum and, on the other hand, created prerequisites for prototyping of defect and virtual planning of surgery using both standard and customized implants [49, 50]. Thus, we face a reasonable question: do we today need Paprosky classification (or any other) to describe acetabular defects?

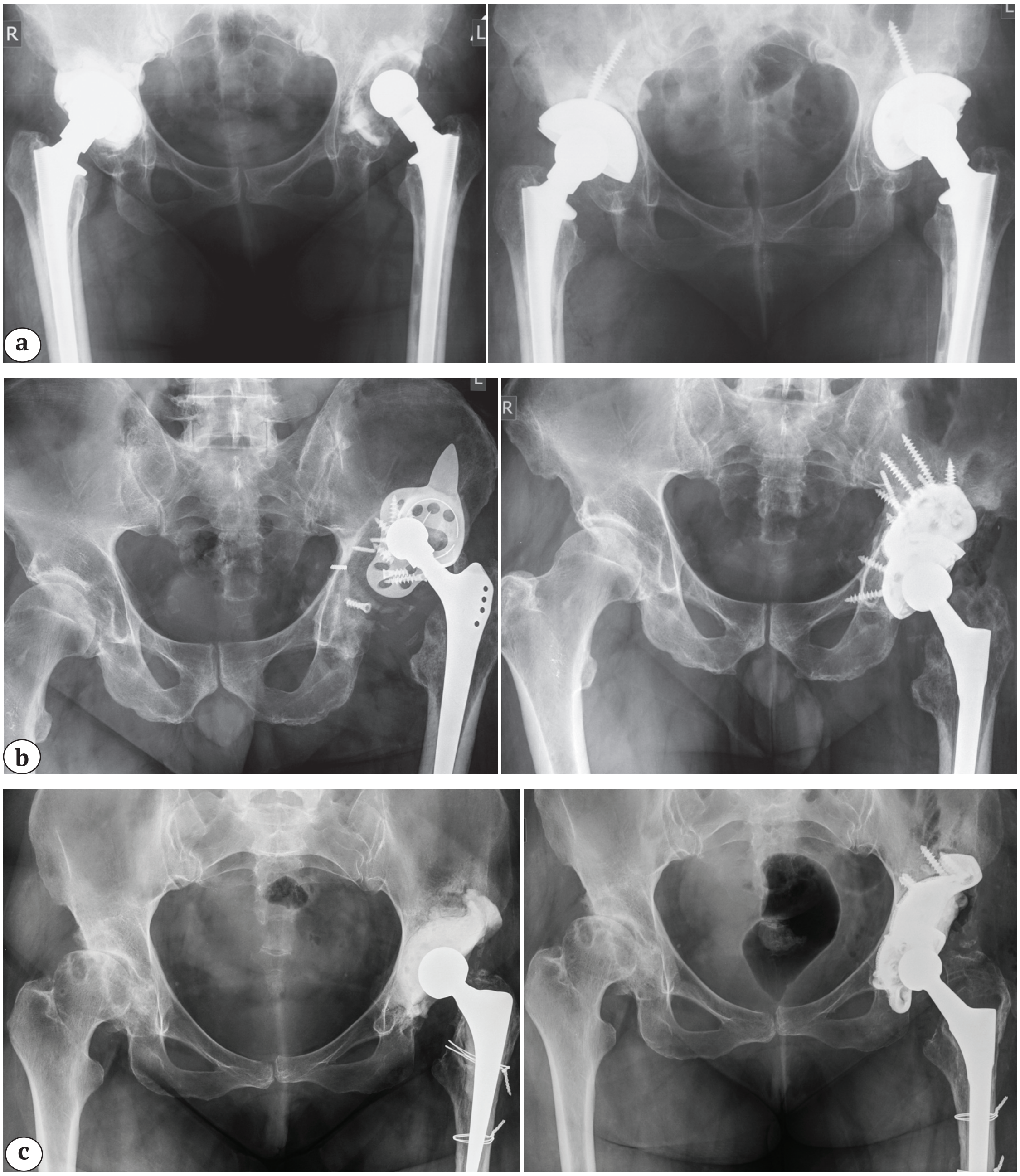


Fig. 9. Three clinical cases with IIIa type defect:
a — contained defect; cementless semi-spherical cups — X-rays prior to revision and 8 years after revision; cups positioning is not optimal but contained pattern of the defect, sufficient large contact area and cementless fixation provided good long term outcome;
b — non-contained defect; semi-spherical cut and customized augment — X-rays at admission and in 3 months after revision;
c — use of customized three-flanges implant – articulating spacer implanted due to periprosthetic infection, X-ray signs of IIIa type defect, side and shape of defect determined the choice of custom-made implant

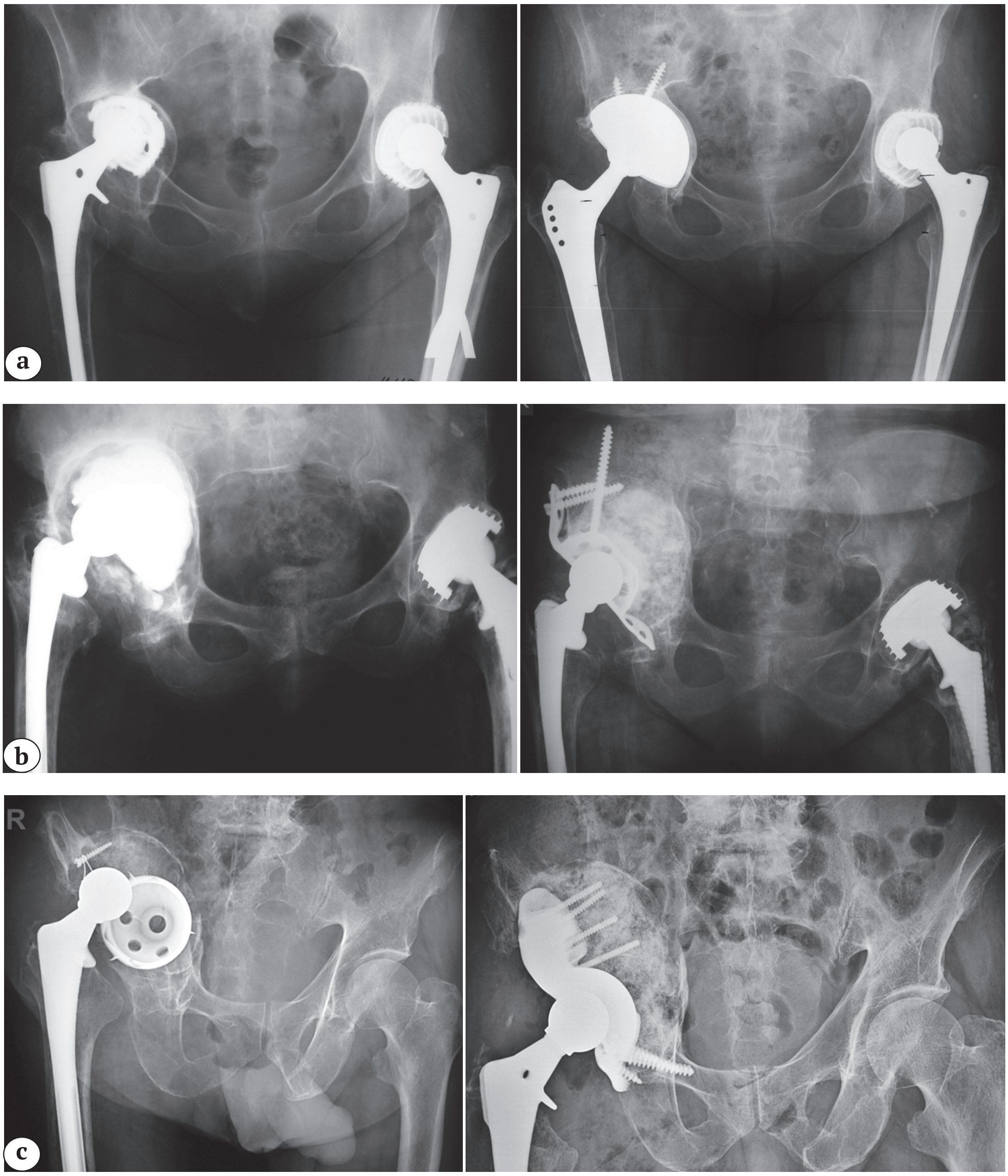


Fig. 10. Three clinical cases of patients with IIIb type defects:
a — contained defect: bone grafting by bone chips, cup of 76 mm; minor migration of inferior component of the cup is visualized 3 years postoperatively along with good compaction of allografts and no osteolysis around the cup, no clinical signs of loosening;
b — contained bigger size defect without damage of walls, bone grafting was used with anti-protrusion Burch-Schneider ring, 8 years after revision;
c — massive defect with loss of medial wall integrity, bone grafting with custom-made implant, outcome in 2 years postoperatively

According to literature this classification is still valid today though having some drawbacks. In contrast to other this system has rather precise anatomical references, when a surgeon with correct perception and understanding of this classification basing on standard overall pelvis X-ray can adequately predict challenges in the operation theatre. We are aware that today the size and location of the periprosthetic defect is not the only question which needs an answer. It's equally important to know the volume of bone loss for planning grafting, presence and location of disruption of the defect wall, expected contact area between implant and host bone, and finally the quality of periprosthetic bone tissue to provide sufficient primary fixation of the implant and screws and then osteointegration. Naturally additional information like high quality CT imaging significantly expands our possibilities. During recent years we are able to substantially improve the quality of obtained images by implementation of new software for clearing the image and receiving a virtual picture maximally reflecting the true situation. However, this process requires high qualification of specialists, vast experience in separation of bone tissue from multiple artifacts (dense scar tissue, metal debris, remains of bone cement). Densitometry criteria of bone density are widely introduced during last years to reflect the bone quality. But we should not forget that bone density and bone capability for regeneration and osteointegration are not synonyms. Besides, there is rather big error in measurements of bone density of the same samples on CTs of different manufacturers. Thus, F. Eggermont et al in their study demonstrated that average difference between various computer tomographic scanners amounted to 7% for assessment of cortical bone, 6% — for trabecular bone, 6% — for mineral density of bone and 12% — for cortical and trabecular areas, during reconstruction the error reached 17% [51].

Thus, today in the widely available research on revision arthroplasty Paprosky classification remains the most used, in majority of cases it allows to determine defect type, to unify evaluation of outcomes and to compare various techniques in more or less similar situations. Do we need a new classification based on 3D-modeling? It appears that not at the moment, while it may lead to excessive detailing in defects description while the major principles of revision arthroplasty remain constant. On the other hand, some substantial additions would be in our opinion very helpful while they will allow to optimize choice of procedure and ensure more precise planning. We mean additional specification of defects basing on such criteria as contained/uncontained defect and pelvis discontinuity. Perhaps, it would be useful to apply two classifications similarly to evaluation of functional outcomes when one scale is not sufficient (for example, Harris Hip Score) and some patient survey is added (Oxford Hip Score or WOMAC). Naturally a questions remains unsolved in respect of volume of bone tissue damage. Above X-rays demonstrate significant difference in defect volume which means that surgical tactics as well as probability of unfavorable outcomes of revisions will most likely be different. Increasingly active introduction of current visualization and prototyping methods greatly expanded out perception on acetabular defects and enabled customized choice of implants, but the principles elaborated during past quarter of a century remain important for understanding the essence of anatomical changes. Respectively, application of Paprosky classification is still actual while it allows surgeons speak the same language and to the large extend determine the choice of surgical tactics. Probably further development of digital techniques in the foreseeable future will broaden our options not only for defect visualization but our capabilities to understand the vitality of host bone, and perhaps then we would need a new classification based on completely new principles.

Competing interests: the authors declare that they have no competing interests.

Funding: the authors have no support or funding to report.

Consent for publication: the patients provided voluntary consent for publication of case data.

References

1. Murylev V.Y., Kukovenko G.A., Elizarov P.M., Ivanenko L.R., Sorokina G.L., Rukin Y.A., Alekseev S.S., Germanov V.G. The first-stage treatment algorithm for deep infected total hip arthroplasty. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2018;24(4):95-104. (In Russ.) DOI: 10.21823/2311-2905-2018-24-4-95-104.
2. Sadovoy M.A., Pavlov V.V., Bazlov V.A., Mamuladze T.Z., Efimenko M.V., Aronov A.M., Panchenko A.A. Potentialities of 3D-visualization in preoperative planning of primary and revision total hip arthroplasty. *Vestnik travmatologii i ortopedii im. N.N. Priorova* [N.N. Priorov Journal of Traumatology and Orthopedics]. 2017;(3):37-42. (In Russ.) DOI: 10.32414/0869-8678-2017-3-37-42.
3. Bozic K.J., Kamath A.F., Ong K., Lau E., Kurtz S., Chan V. et al. Comparative Epidemiology of Revision Arthroplasty: Failed THA Poses Greater Clinical and Economic Burdens Than Failed TKA. *Clin Orthop Relat Res.* 2015;473(6):2131-2138. DOI: 10.1007/s11999-014-4078-8.
4. Yoon P.W., Lee Y.K., Ahn J., Jang E.J., Kim Y., Kwak H.S. et al. Epidemiology of hip replacements in Korea from 2007 to 2011. *J Korean Med Sci.* 2014;29(6):852-858. DOI: 10.3346/jkms.2014.29.6.852.
5. Gwam C.U., Mistry J.B., Mohamed N.S., Thomas M., Bigart K.C., Mont M.A., Delanois R.E. Current epidemiology of revision total hip arthroplasty in the United States: National Inpatient Sample 2009 to 2013. *J Arthroplasty.* 2017;32(7):2088-2092. DOI: 10.1016/j.arth.2017.02.046.
6. Patel A., Pavlou G., Mújica-Mota R.E., Toms A.D. The epidemiology of revision total knee and hip arthroplasty in England and Wales: a comparative analysis with projections for the United States. A study using the National Joint Registry dataset. *Bone Joint J.* 2015; 97-B(8):1076-1081. DOI: 10.1302/0301-620X.97B8.35170.
7. Kasch R., Assmann G., Merk S., Barz T., Melloh M., Hofer A. et al. Economic analysis of two-stage septic revision after total hip arthroplasty: What are the relevant costs for the hospital's orthopedic department? *BMC Musculoskelet Disord.* 2016;17:112. DOI: 10.1186/s12891-016-0962-6.
8. Koenig L., Feng C., He F., Nguyen J.T. The effects of revision total hip arthroplasty on medicare spending and beneficiary outcomes: implications for the comprehensive care for joint replacement model. *J Arthroplasty.* 2018;33(9):2764-2769.e2. DOI: 10.1016/j.arth.2018.05.008.
9. Kurtz S.M., Lau E.C., Ong K.L., Adler E.M., Kolisek F.R., Manley M.T. Which clinical and patient factors influence the national economic burden of hospital readmissions after total joint arthroplasty? *Clin Orthop Relat Res.* 2017;475(12):2926-2937. DOI: 10.1007/s11999-017-5244-6.
10. Tikhilov R.M., Shubnyakov I.I., Kovalenko A.N., Totoyev Z.A., Lyu B., Bilyk S.S. The structure of early revisions after hip replacement. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia] 2014;(2): 5-13.(InRuss.).DOI:10.21823/2311-2905-2014-0-2-5-13.
11. Badarudeen S., Shu A.C., Ong K.L., Baykal D., Lau E., Malkani A.L. Complications after revision total hip arthroplasty in the medicare population. *J Arthroplasty.* 2017;32(6):1954-1958. DOI: 10.1016/j.arth.2017.01.037.
12. Khatod M., Cafri G., Inacio M.C., Schepps A.L., Paxton EW., Bini S.A. Revision total hip arthoplasty: factors associated with re-revision surgery. *J Bone Joint Surg Am.* 2015;97(5):359-366. DOI: 10.2106/JBJS.N.00073.
13. Nichols C.I., Vose J.G. Clinical outcomes and costs within 90 days of primary or revision total joint arthroplasty. *J Arthroplasty.* 2016;31(7):1400-1406.e3. DOI: 10.1016/j.arth.2016.01.022.
14. Jafari S.M., Coyle C., Mortazavi S.M., Sharkey P.F., Parvizi J. Revision hip arthroplasty: infection is the most common cause of failure. *Clin Orthop Relat Res.* 2010;468(8):2046-2051. DOI: 10.1007/s11999-010-1251-6.
15. Sheridan G.A., Kelly R.M., McDonnell S.M., Walsh F., O'Byrne J.M., Kenny P.J. Primary total hip arthroplasty: registry data for fixation methods and bearing options at a minimum of 10 years. *Ir J Med Sci.* 2018 Dec 17. DOI: 10.1007/s11845-018-1948-1. [Epub ahead of print].
16. Guide to hip surgery. Ed. by R.M. Tikhilov, I.I. Shubnyakov. SPb, 2014. Vol.1, Ch.7. pp. 221-257.
17. Pavlov V.V., Kirilova I.A., Efimenko M.V., Bazlov V.A., Mamuladze T.Z. Two-stage revision hip replacement patiens with severe acetabulum defect (case report). *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia] 2017;23(4):125-133. (In Russ.) DOI: 10.21823/2311-2905-2017-23-4-125-133.
18. Campbell D.G., Garbuz D.S., Masri B.A., Duncan C.P. Reliability of acetabular bone defect classification systems in revision total hip arthroplasty. *J Arthroplasty.* 2001;16(1):83-86.
19. Jenkins D.R., Odland A.N., Sierra R.J., Hanssen A.D., Lewallen D.G. Minimum five-year outcomes with porous tantalum acetabular cup and augment construct in complex revision total hip arthroplasty. *J Bone Joint Surg Am.* 2017;99(10):e49. DOI: 10.2106/JBJS.16.00125.
20. Kavalerskiy G.M., Murylev V.Y., Rukin Y.A., Elizarov P.M., Lychagin A.V., Tselisheva E.Y. Three-dimensional models in planning of revision hip arthroplasty with complex acetabular defects. *Indian J Orthop.* 2018;52(6):625-630. DOI: 10.4103/ortho.IJOrtho_556_16.
21. Pierannunzii L., Zagra L. Bone grafts, bone graft extenders, substitutes and enhancers for acetabular reconstruction in revision total hip arthroplasty. *EFORT Open Rev.* 2017;1(12):431-439. DOI: 10.1302/2058-5241.160025.
22. Gross A.E., Allan D.G., Catre M., Garbuz D.S., Stockley I. Bone grafts in hip replacement surgery. The pelvic side. *Orthop Clin North Am.* 1993;24(4):679-695.
23. Parry M.C., Whitehouse M.R., Mehendale S.A., Smith L.K., Webb J.C., Spencer R.F., Blom A.W. A comparison of the validity and reliability of established bone stock loss

classification systems and the proposal of a novel classification system. *Hip Int.* 2010;20(1):50-55.
24. Paprosky W.G., Perona P.G., Lawrence J.M. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. *J Arthroplasty.* 1994;9(1):33-44.
25. D'Antonio J.A., Capello W.N., Borden L.S., Bargar W.L., Bierbaum B.F., Boettcher W.G. et al. Classification and management of acetabular abnormalities in total hip arthroplasty. *Clin Orthop Relat Res.* 1989;(243):126-137.
26. Saleh K.J., Holtzman J., Gafni ASaleh L., Jaroszynski G., Wong P., Woodgate I. et al. Development, test reliability and validation of a classification for revision hip arthroplasty. *J Orthop Res.* 2001;19(1):50-56.
27. Ahmad A.Q., Schwarzkopf R. Clinical evaluation and surgical options in acetabular reconstruction: A literature review. *J Orthop.* 2015;12(Suppl2):S238-243. DOI: 10.1016/j.jor.2015.10.011.
28. Amirouche F., Solitro G.F., Walia A., Gonzalez M., Bobko A. Segmental acetabular rim defects, bone loss, oversizing, and press fit cup in total hip arthroplasty evaluated with a probabilistic finite element analysis. *Int Orthop.* 2017;41(8):1527-1533. DOI: 10.1007/s00264-016-3369-y.
29. Baauw M., van Hooff M.L., Spruit M. Current construct options for revision of large acetabular defects: a systematic review. *JBJS Rev.* 2016;4(11). pii: 10.2106/JBJS.RVW.15.00119. DOI: 10.2106/JBJS.RVW.15.00119.
30. Lee J.M., Kim T.H. Acetabular Cup Revision Arthroplasty Using Morselized Impaction Allograft. *Hip Pelvis.* 2018;30(2):65-77. DOI: 10.5371/hp.2018.30.2.65.
31. Horas K., Arnholdt J., Steinert A.F., Hoberg M., Rudert M., Holzapfel B.M. Acetabular defect classification in times of 3D imaging and patient-specific treatment protocols. *Orthopade.* 2017;46(2):168-178. DOI: 10.1007/s00132-016-3378-y.
32. Mäkinen T.J., Kuzyk P., Safir O.A., Backstein D., Gross A.E. Role of cages in revision arthroplasty of the acetabulum. *J Bone Joint Surg Am.* 2016;98(3):233-242. DOI: 10.2106/JBJS.O.00143.
33. Wassilew G.I., Janz V., Perka C., Müller M. [Treatment of acetabular defects with the trabecular metal revision system]. *Orthopade.* 2017;46(2):148-157. (In German). DOI: 10.1007/s00132-016-3381-3.
34. Gustilo R.B., Pasternak H.S. Revision total hip arthroplasty with titanium ingrowth prosthesis and bone grafting for failed cemented femoral component loosening. *Clin Orthop Relat Res.* 1988;(235):111-119.
35. Sheth N.P., Melnic C.M., Paprosky W.G. Acetabular distraction: an alternative for severe acetabular bone loss and chronic pelvic discontinuity. *Bone Joint J.* 2014;96-B(11 Supple A):36-42. DOI: 10.1302/0301-620X.96B11.34455.
36. Sheth N.P., Nelson C.L., Springer B.D., Fehring T.K., Paprosky W.G. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. *J Am Acad Orthop Surg.* 2013;21(3):128-139. DOI: 10.5435/JAAOS-21-03-128.
37. Bettin D., Katthagen B.D. [The German Society of Orthopedics and Traumatology classification of bone defects in total hip endoprostheses revision operations]. *Z Orthop Ihre Grenzgeb.* 1997;135(4):281-284. (In German). DOI: 10.1055/s-2008-1039389.
38. Koob S., Scheidt S., Randau T.M., Gathen M., Wimmer M.D., Wirtz D.C., Gravius S. [Biological downsizing: Acetabular defect reconstruction in revision total hip arthroplasty]. *Orthopade.* 2017;46(2):158-167. (In German). DOI: 10.1007/s00132-16-3379-x.
39. Telleria J.J., Gee A.O. Classifications in brief: Paprosky classification of acetabular bone loss. *Clin Orthop Relat Res.* 2013;471(11):3725-3730. DOI: 10.1007/s11999-013-3264-4.
40. Yu R., Hofstaetter J.G., Sullivan T., Costi K., Howie D.W., Solomon L.B. Validity and reliability of the Paprosky acetabular defect classification. *Clin Orthop Relat Res.* 2013;471(7):2259-2265. DOI: 10.1007/s11999-013-2844-7.
41. Jerosch J., Steinbeck J., Fuchs S., Kirchhoff C. [Radiologic evaluation of acetabular defects on acetabular loosening of hip alloarthroplasty]. *Unfallchirurg.* 1996;99(10):727-733. (In German).
42. Gozzard C., Blom A., Taylor A., Smith E., Learmonth I. A comparison of the reliability and validity of bone stock loss classification systems used for revision hip surgery. *J Arthroplasty.* 2003;18(5):638-642.
43. Claus A.M., Engh C.A. Jr, Sychterz C.J., Xenos J.S., Orishimo K.F., Engh C.A. Sr. Radiographic definition of pelvic osteolysis following total hip arthroplasty. *J Bone Joint Surg Am.* 2003;85-A(8):1519-1526.
44. Safir O., Lin C., Kosashvili Y., Mayne I.P., Gross A.E., Backstein D. Limitations of conventional radiographs in the assessment of acetabular defects following total hip arthroplasty. *Can J Surg.* 2012;55(6):401-407. DOI: 10.1503/cjs.000511.
45. Paprosky W.G., O'Rourke M., Sporer S.M. The treatment of acetabular bone defects with an associated pelvic discontinuity. *Clin Orthop Relat Res.* 2005;441:216-220.
46. Sheth N.P., Melnic C.M., Brown N., Sporer S.M., Paprosky W.G. Two-centre radiological survivorship of acetabular distraction technique for treatment of chronic pelvic discontinuity. *Bone Joint J.* 2018;100-B(7):909-914. DOI: 10.1302/0301-620X.100B7.BJJ-2017-1551.R1.
47. Liu B., Gao Y.H., Ding L., Li S.Q., Liu J.G., Qi X. Computed Tomographic Evaluation of Bone Stock in Patients With Crowe Type III Developmental Dysplasia of the Hip: Implications for Guiding Acetabular Component Placement Using the High Hip Center Technique. *J Arthroplasty.* 2018;33(3):915-918. DOI: 10.1016/j.arth.2017.10.021.
48. Chen M., Luo Z.L., Wu K.R., Zhang X.Q., Ling X.D., Shang X.F. Cementless Total Hip Arthroplasty With a High Hip Center for Hartofilakidis Type B Developmental Dysplasia of the Hip: Results of Midterm Follow-Up. *J Arthroplasty.* 2016;31(5):1027-1034. DOI: 10.1016/j.arth.2015.11.009.
49. Kovalenko A.N., Tikhilov R.M., Bilyk S.S., Shubnyakov I.I., Cherkasov M.A., Denisov A.O. Positioning of custom-made acetabular components at revision hip arthroplasty: do they really match as "a key and a lock"? *Vestnik travmatologii i ortopedii im. N.N. Priorova* [N.N. Priorov Journal of Traumatology and Orthopedics]. 2017;(4):31-37. (In Russ.). DOI: 10.32414/0869-8678-2017-4-31-37.
50. Korytkin A.A., Zakharova D.V., Novikova Y.S., Gorbatov R.O., Kovaldov K.A., El Moudni Y.M. Custom triflange acetabular components in revision hip replacement (experience review). *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2017;23(4):101-111. (In Russ.) DOI: 10.21823/2311-2905-2017-23-4-101-111.

51. Eggermont F., Derikx L.C., Free J., van Leeuwen R., van der Linden Y.M., Verdonschot N., Tanck E. Effect of different CT scanners and settings on femoral failure loads calculated by finite element models. *J Orthop Res.* 2018 Mar 6. DOI: 10.1002/jor.23890. [Epub ahead of print].

INFORMATION ABOUT AUTHORS:

Rashid M. Tikhilov — Dr. Sci. (Med.), Professor, Director of Vreden Russian Research Institute of Traumatology and Orthopedics; professor of Traumatology and Orthopedics Department, Mechnikov North-Western State Medical University, St. Petersburg, Russian Federation

Igor I. Shubnyakov — Dr. Sci. (Med.), Chief Researcher, Vreden Russian Research Institute of Traumotology and Orthopedics, St. Petersburg, Russian Federation

Alexei O. Denisov – Cand. Sci. (Med), Academic Secretary, Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russian Federation