Joint Diseases and Related Surgery

Jt Dis Relat Surg
2022;33(1):9-16

ORIGINAL ARTICLE

The roof step cut: A novel technique for bony reconstruction of acetabular roof deficiency during total hip replacement

Zoltán Csernátony, MD[1], Gyula Győrfi, MD[1], Sándor Barna, MD[2], Sándor Manó, MSc[3], János Szabó, MD[1], Lei Zhang, MD[1]

[1]Department of Orthopaedic Surgery, Faculty of Medicine, University of Debrecen, Debrecen, Hungary
[2]Department of Radiology, Scanomed Ltd, Debrecen, Hungary
[3]Laboratory of Biomechanics, Faculty of Medicine, University of Debrecen, Debrecen, Hungary

Developmental dysplasia of the hip (DDH) is one of the most common causes of secondary osteoarthritis (OA) in early adulthood. The more serious the pathology is, the more challenging the total hip replacement (THR) would be. Bony coverage is one of the most important factors regarding implantation of the acetabular cup during surgery.[1] Although various methods have been described in the literature,[2-5] the variety of choices indicates that an ideal option is still missing. As more and more patients decide to undergo THR at a relatively young age, the right choice for acetabular augmentation has become a rather frequent question during clinical practice.

Received: June 28, 2021
Accepted: November 14, 2021
Published online: March 25, 2022

Correspondence: Lei Zhang MD. Department of Orthopaedic Surgery, Faculty of Medicine, University of Debrecen, 4032 Debrecen, Hungary.

E-mail: leizhang@med.unideb.hu

Doi: 10.52312/jdrs.2022.266

Citation: Csernátony Z, Győrfi G, Barna S, Manó S, Szabó J, Zhang L. The roof step cut: A novel technique for bony reconstruction of acetabular roof deficiency during total hip replacement. Jt Dis Relat Surg 2022;33(1):9-16.

ABSTRACT

Objectives: This study aims to present a new technique, the roof step cut (RSC), for acetabular augmentation of hip dysplasia.

Patients and methods: Between December 2008 and March 2020, we applied the RSC technique in a total of 48 hips of 41 patients (2 males, 39 females; mean age: 50.1±9.5 years; range, 30 to 75 years) with Hartofilakidis type A, B, C hip dysplasia. The RSC technique uses a L-shaped graft cut from the femoral head. The graft is partially inside the acetabulum and partially on the lateral aspect of the ilium. It is fixed with two screws at a 45° angle allowing simultaneous distalization and lateral covering of the cementless cup. Follow-up was done at six weeks, three months, and annually thereafter using standard pelvis anteroposterior X-ray and function scores. The 99mTc bone scintigraphy examination was also performed at around two weeks, six months, and 12 months postoperatively to evaluate the healing process of the graft.

Results: The mean follow-up time was 59.6±25.6 (range, 12 to 109) months. No significant center-edge angle changes and no contiguous radiolucent zones at the bone-prosthesis interface were observed at the final follow-up. The single-photon emission tomography (SPECT) showed the activity of the bone graft gradually increased after surgery and became almost the same as the reference area after 12 months. Functional evaluation showed a significant improvement after the operation. No complication directly related to the technique was observed.

Conclusion: In the short-term follow-up, the RSC technique is a reliable procedure for acetabular augmentation of hip dysplasia, providing enough coverage for the cementless cup and assuring proper stability.

Keywords: Hip dysplasia, osteoarthritis, roof step cut, total hip replacement.

To achieve better biomechanical environment for the cup, comparing to the high hip center (HHC),[6,7] it is preferred to restore the primary hip center or, at least, close to it.[8] For the triangle-shaped hiatus in the inner superolateral aspect of the acetabulum, most authors have suggested that host bone coverage should be at least 70% to provide enough primary stability; otherwise, bone grafting is needed.[9] However, we should keep in mind that cup loosening is one of the most frequent causes of revision currently, even for cases without hip dysplasia. To implant the cup in the primary rotational center, we need to construct a reliable bony roof.

During the last decade, we have developed and performed the new technique called the roof step cut (RSC) for acetabular augmentation. In this study, we aimed to introduce the surgical technique and present the results of short-term follow-up.

PATIENTS AND METHODS

This observational study was conducted at University of Debrecen, Faculty of Medicine, Department of Orthopaedic Surgery between December 2008 and March 2020. Patients with hip dysplasia, Hartofilakidis classification type A-C, were included and those with acetabular fracture, or serious bone metabolic disease were excluded. Finally, a total of 48 hips of 41 patients (2 males, 39 females; mean age: 50.1±9.5 years; range, 30 to 75 years), that underwent primary THR combined with the RSC technique were included. The Hartofilakidis classification was used to evaluate the severity of the acetabular deformity/dysplasia before the operation. A written informed consent was obtained from each patient. The study protocol was approved by the Clinical Center Regional Istitutional Research Ethics Committee (No./Date: DE RKEB/IKEB 5787-2021). The study was conducted in accordance with principles of the Helsinki Declaration.

Surgical Technique

Patient preparation

All operations are performed under general anesthesia. The patients are in supine position with a slight elevation of the affected hip joint, keeping the pelvis in horizontal line. Following normal procedures to disinfect the operating area and sterile sheets are laid out.

Exposure

A standard anterolateral approach is used during all the surgeries, using the physiological gap between the gluteus medius and tensor fasciae latae muscles. After exposing the joint, the capsule is partially excised and the femoral head is removed with an oscillating saw after dislocation.

Acetabulum evaluation and preparation

After localizing the primary acetabulum and its depth, we perform the achievable reaming usually with the smallest diameter reamer (Figure 1a); however, the technique may differ according to the intraoperative situation. In many cases after reaming, a triangle shaped bony defect is visible on the inner superolateral surface of the acetabulum. Using trial cups, the extent of the defect is determined. Bone grafting is usually needed, if more than 30% of the cup is uncovered. In our practice, the main goal is to achieve a total bony coverage of the cup, even if the uncovered part is less than 30%.

Host surface preparation

To perform the RSC technique, we make a horizontal cut at the cranial wall of the acetabulum, which is supplemented by a vertical cortical refreshing cut at the lateral aspect of the ilium, resulting in a rectangular spongiotic host surface (Figure 1b-d).

Graft preparation and fixation

After measuring the size of the prepared host area, we sculpt the femoral head to achieve a right-angled L-shaped profile graft with possibly preserved external cortical and spongiotic surface (Figure 1e, f). The horizontal part of the graft should be a bit thicker to allow simultaneous distalization and lateral covering of the cup. After the graft is fitted onto the intra- and supra-acetabular bed, it is fixed temporarily by a Kirschner wire. The final fixation is carried out by the insertion of two compression screws with a 45-degree angle (Figure 1g).

Cup insertion

By undermining the overhanging graft, we achieve reliable contact with the cranial aspect of the cup (Figure 1h). The size is checked again with trial cups and, then, the uncemented cup is inserted in a press-fit way and secured by one or two complementary screws, if necessary (Figures 1i).

Femoral preparation and stem implantation

The medullary canal of the femur is opened, prepared to the desired size with reamers and, in most cases, the final cementless stem is implanted.

Reduction, examination, stability test and wound closing

After the final femoral head is implanted, the hip is reduced, the range of motion and the stability is tested. Rinsing the incision area with normal saline and betadine, the wound is closed layer by layer. A suction drainage is left for 48 h in the joint, if needed.

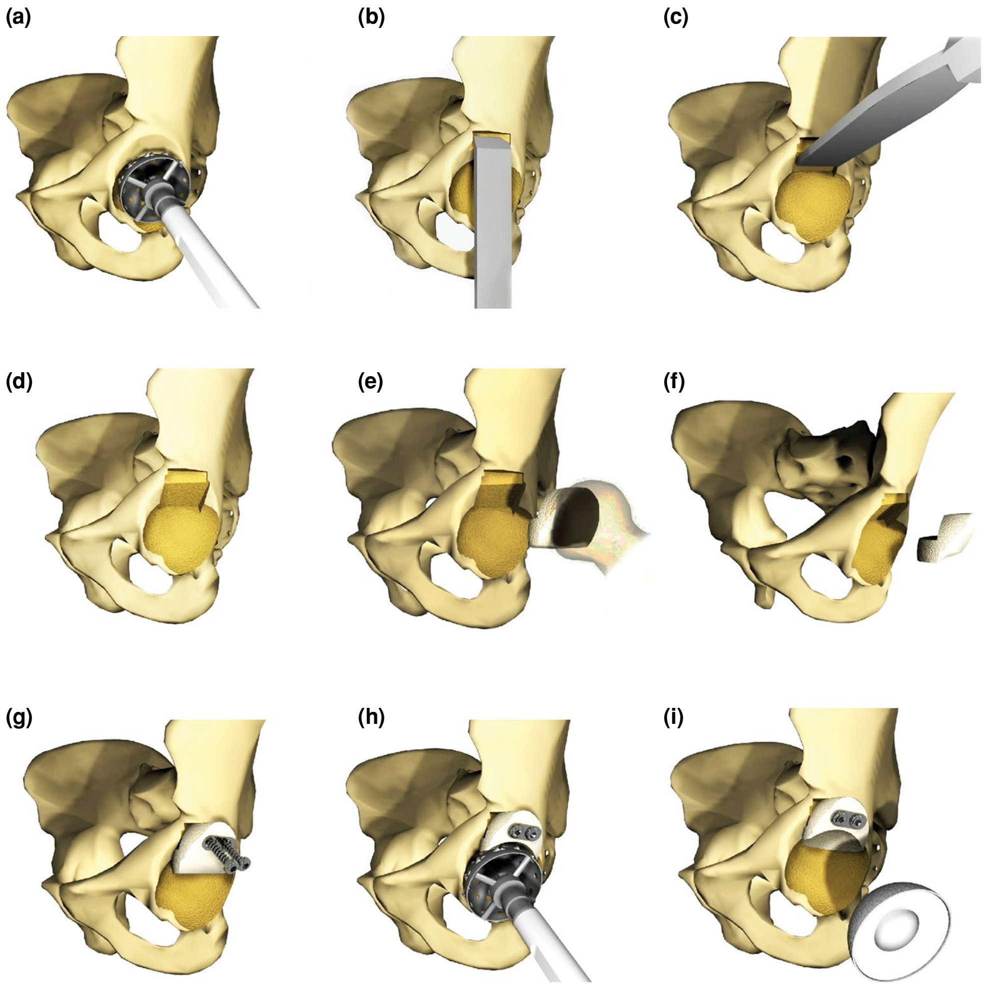

FIGURE 1. The RSC technique. **(a)** Acetabulum reaming; **(b)** Vertical cut at the lateral aspect of the ilium; **(c)** Horizontal cut at the cranial wall of the acetabulum; **(d)** Achieving step-cut spongiotic host surface; **(e)** Assessing and sculpting the femoral head; **(f)** The right-angled L-shaped graft; **(g)** Fixing the graft with two compression screws at 45°; **(h)** Undermining the overhanging graft; **(i)** Inserting the cementless cup in a press-fit way.
RSC: Roof step cut.

Follow-up assessment

After surgery, we continuously followed the patients at six weeks, three months, and annually thereafter. At each time point, a standard pelvis anteroposterior X-ray was done. The center-edge (CE) angle was measured to evaluate the graft resorption, which is the angle between the vertical line of the socket center and the lateral edge of the graft bone. Evidence of loosening was decided according to the methods of Gruen et al.[10] and DeLee and Charnley.[11] To dynamically observe the changes of the graft, 99mTc bone scintigraphy was performed around two weeks after the operation before the patient was discharged from hospital to check the edema effect, six months, and one year postoperatively to check bone necrosis or graft failure.[12] Three-phase bone scan were done with additional single-photon emission tomography (SPECT)/computed tomography (CT) in the late phase. The first phase was started after the 600MBq 99mTc-MDP radiopharmaceuticals injection with 60×1 sec timing and 64×64 matrix size focusing on hip region in anterior and posterior view. The blood pool phase was a 180-sec long static examination with same matrix size and image location. The third phase was a whole-body planar scan in anterior and posterior view and a SPECT/CT from a hip region. Examinations were all performed on 16-slice

SPECT/CT system (AnyScan SPECT/CT, MEDISO, Budapest, Hungary). The following SPECT parameters were used: 128×128-word mode matrix, 64 views at 30 sec per view, steep and shoot modality, body contouring, and low-energy all-purpose collimator. The reconstruction method was Ordered Subset Expectation Maximization (OSEM) with a butterworth prefilter. In the anterior view of perfusion phase images, manually drawn circular regions of interest (ROIs) were set up on the graft bone area and on the contralateral area as reference. Activity ratio between the two sites was calculated.

Regarding functional condition, we applied the Western Ontario and McMaster Universities Arthritis Index (WOMAC) and Oswestry Disability Index (ODI) before surgery and later at each follow-up time point. The WOMAC is widely used in the evaluation of hip and knee OA. It is a self-administered questionnaire consisting of 24 items divided into three subscales: pain (5 items), stiffness (2 items), and physical function (17 items). The test questions are scored on a scale of 0-4, which correspond to: none (0), mild (1), moderate (2), severe (3), and extreme (4). Higher scores on the WOMAC indicate worse pain, stiffness, and functional limitations. The ODI consists of 10 patient-completed questions in which the response options are presented as six-point Likert scales. Scores range from 0% (no disability) to 100% (most severe disability).

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 19.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were presented in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequency. The paired sample t-tests were used for intra-group comparison. Follow-up activity ratio comparison was analyzed by non-parametric test. A p value of <0.05 was considered statistically significant.

RESULTS

Demographic data and clinical results are given in Table I. Cemented cups were only used in two cases, while cementless cups were implanted and almost half were Hartofilakidis type B hips. The mean follow-up time was 59.6±25.6 (range, 12 to 109) months.

Figure 2 shows the graft remodeling process at different time points of one case. No evidence of graft resorption was observed. The mean CE angle at six weeks, three months, 12 months, and the final follow-up were 51.3±3.0°, 50.8±2.6°, 50.6±2.3°, and 49.8±1.8°, respectively (p>0.05). No contiguous radiolucent zones at the bone-prosthesis interface were observed in the three DeLee & Charnley zones and in the seven Gruen zones at 12 months after surgery. Three (7.3%) cases had osteolysis around the acetabular and two (4.9%) around the femoral components. Osteolysis was most common in DeLee and Charnley Zone II and III of the acetabular components and Gruen Zone VII of the femoral component.

Scintigraphy follow-up was fully performed in 23 cases, four patients only completed the examination in the second week after surgery, other 14 cases did not complete the final follow-up. The mean ROI counts activity ratio (graft *vs* reference) for whole body was 2.14±0.99, 1.52±0.48, and 1.31±0.38 at two weeks, six months, and 12 months, respectively. For SPECT of the graft, these values were 0.84±0.31, 0.87±0.42, and 0.99±0.65, respectively. The Kruskal-Wallis test showed for the whole body there was a significant difference between the groups (H=9.129, p=0.01) (Figure 3a), and pairwise comparisons further showed a significant difference existed between two weeks and 12 months (p=0.008). For SPECT, there was no significant difference between the groups (H=0.189, p=0.910) (Figure 3b). However, the activity of the bone graft gradually

TABLE I
Patient characteristics and clinical results

Variables	n	%	Mean	Range
Age at surgery (year)			50.1	30-75
Sex				
Male	2			
Female	39			
Hips	48			
Implanted cup type				
Cementless	46	95.8		
Cemented cups	2	4.2		
Laterality				
Unilateral	34	82.9		
Bilateral	7	17.1		
Hartofilakidis classification				
Type A	18	37.5		
Type B	24	50.0		
Type C	6	12.5		
Follow-up (month)			59.6	12-109
Graft resorption	0			
Cup loosening	3	6.3		

increased after surgery and became almost the same as the reference area after 12 months. Figure 4 shows the dynamic changes of the whole-body planar scan and SPECT at three time points after surgery.

The WOMAC and ODI significantly improved after the operation. The average ODI improved from 36.6% (25 to 40%) preoperatively to 16.8% (12 to 20%) at the final follow-up ($p<0.05$). The mean WOMAC improved from 88.3±6.2 points to 38.0±5.8 points ($p<0.05$). Figure 5 shows the average change of both the scores along with time.

The cup had to be revised due to loosening in three cases. Two of them occurred following direct high-energy trauma (traffic accidents) affecting the

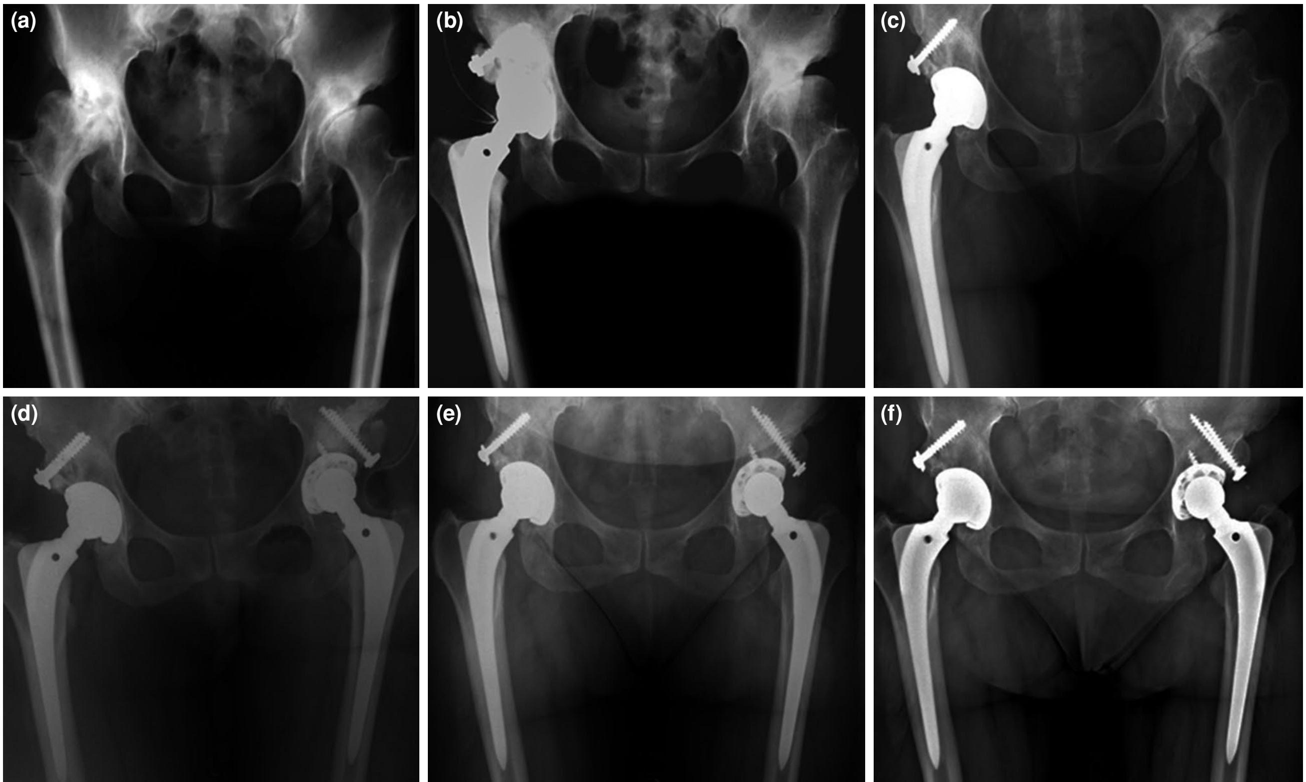

FIGURE 2. A 48-year-old female patient with Hartofilakidis type B hip dysplasia. **(a)** Preoperative X-ray; **(b)** Postoperative immediate X-ray; **(c)** Two years after surgery; **(d)** Three years follow-up of the right hip and postoperative X-ray of the left side; **(e)** Five years postoperative of the right side and two years of the left; **(f)** Eight years postoperative of the right side and five years of the left. Both grafts are completely incorporated with the host bone.

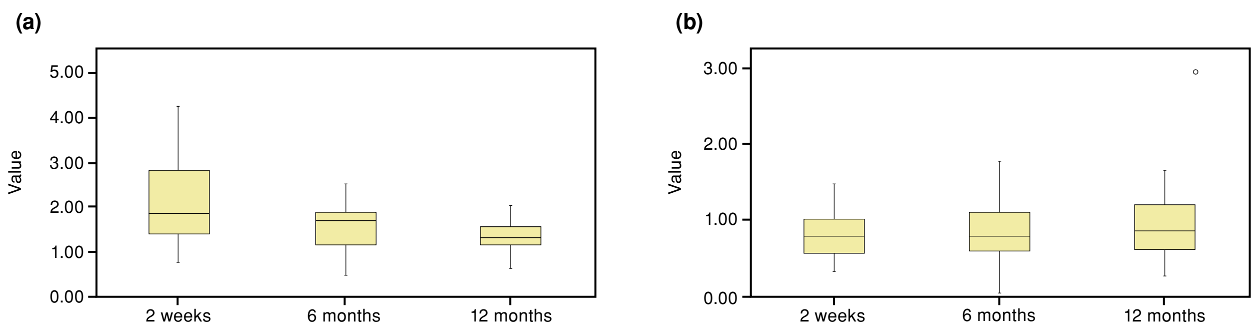

FIGURE 3. Independent-Sample Kruskal-Wallis test between the time groups **(a)** Whole-body planar scan. There was significant difference between the groups (H=9.129, p=0.01); **(b)** SPECT, there was no significant difference between the groups (H=0.189, p=0.910).
SPECT: Single-photon emission tomography.

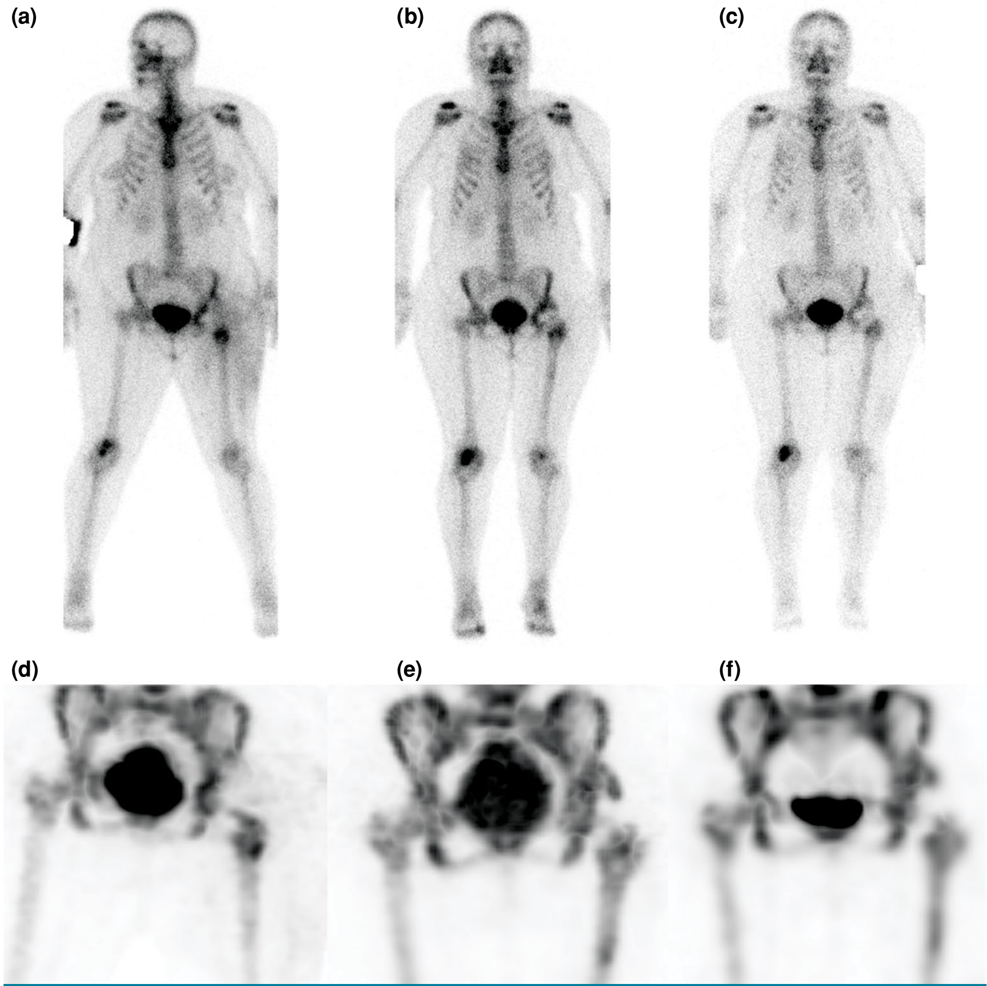

FIGURE 4. Follow-up scintigraphy after surgery. **(a-c)** Whole-body planar scintigraphy at two weeks, six months, and 12 months after surgery, which showed the signal gradually decreased over time; **(d-f)** SPECT MIP of the graft at two weeks, six months, and 12 months after surgery, which showed on the left operated side of the hip, signal at the graft area gradually increased and became almost the same as the contralateral side at 12 months.
SPECT: Single-photon emission tomography; MIP: Maximum intensity projection.

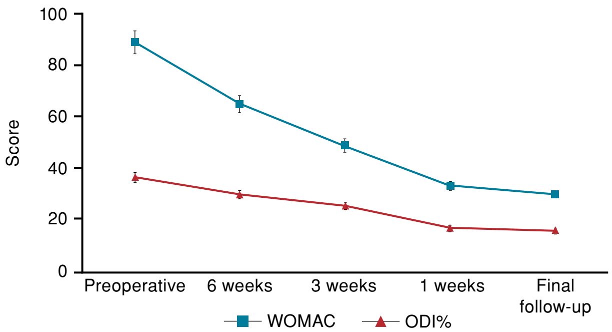

FIGURE 5. Average WOMAC and ODI scores before and after the operation.
WOMAC: McMaster Universities Arthritis Index; ODI: Oswestry Disability Index.

operated hip. One case had to be revised with an anti-protrusion cage with cemented cup, while the other was revised by a cementless cup. One patient underwent a Girdlestone operation due to metastasis of a colon tumor in the acetabulum causing aseptic loosening. No complication directly related to the bony augmentation was observed.

DISCUSSION

Our clinical results showed that, with an L-shaped bone graft for acetabular augmentation of dysplastic hip joints, satisfying clinical results and total cup coverage can be achieved.

In the literature, different techniques have been reported about THR for DDH and the results are quite various, as well. Some authors prefer proximal cup placement, as there is no need of bone grafting, better cup coverage, and shorter operation time. However, restoring the primary rotational center is still considered by most of the authors as the best cup position, as both the HHC and lateral cup placement (LCP) techniques have higher complication rates.[13,14] In addition, the rotational axis of two hips would be parallel to the ground, if the cup is restored in the primary rotational center, the gait would be more harmonic and the asymmetric load on the lumbar spine would decrease. The Trendelenburg limping may also disappear by increasing the tension of the gluteus medius and minimus. The use of cement during bone grafting is also a controversial topic, as cemented and uncemented THR can both achieve good results, if carried out well.[15,16] We believe that, in the presence of good bone quality, the cementless cup is a better choice. As previously mentioned, as more and more young DDH patients decide to undergo THR therapy, press-fit cementless cup is suitable for the good bone quality with satisfactory stability. It is more likely that these young patients would need hip revision surgery later in their lives, and cementless cup can offer more choices for the surgeon and also lower the operation difficulty level.

Compared to other augmentation methods, the RSC technique has several advantages. Autologous bone graft harvested from the femoral head easily achieves incorporation. In this study, by postoperative sequential scintigraphy examinations, early assessment (Week 2) after surgery showed edema effect in the graft area. It is reported that bone scintigraphy performed early (Days 2 to 11) after surgery allows assessment of graft microperfusion, with graft survival reliant on intact blood flow during this critical period.[17] The six-month and 12-month examinations in our study showed an increased uptake of the radioactive tracer, by which we could predict uncomplicated healing course was achieved.[12] The activity ratio decreased significantly on the whole-body planar scintigraphy at 12 months. The reason is that ROIs were drawn on summed images and from the detector view all counts were added, including bone, skin, muscle. Due to the trauma and tissue edema at early stage after surgery, more radioactive tracers distributed on the operated side. For SPECT, ROIs could be drawn more precisely on three-dimensional images and, may be also as the local vascularization was limited, we did not observe significant changes of the activity ratio. However, the activity of the graft bone gradually became almost the same as the reference area after 12 months, which proved good viability and incorporation. The novelty of our technique is reflected in several details. Perpendicular L-shaped bone graft for DDH was only reported by Radojevič[18] in 1990. However, in his study, the compression screw was inserted in horizontal direction. Biomechanically it has a limited mechanical effect on the horizontal part of the graft which can cause instability and produce more stress on the screws. Tilting the screws by 45° could generate compression effect vertically and horizontally. Therefore, it could achieve better stability. During previous biomechanical experiments, we found that the RSC technique has superior stability than other lateral augmentation methods.[19] The inner spongiotic surface is suitable for bone incorporation with the step-cut acetabular roof. Studies have shown that the force perpendicular to the bony surface is most likely to act in favor of appropriate healing.[20,21] The horizontal part of the L-shaped graft usually is sculpted thicker, allowing simultaneous distalization and lateral covering of the cup. The impaction force on the cup would also further stabilize the graft. Iida et al.[22] and Oe et al.[23] published a series of studies on differently shaped femoral bulk bone used as grafts for DDH cases, but their "L-shaped grafts" were not right-angled ones and, in most cases, they used cemented cups. Although their follow-up showed no loosening, we still favor the press-fit cementless cup in view of possible revision in the future. The reason behind that is there is no way to prevent leakage of the liquid cement into the gap between the pelvic bone and the graft, and it may inhibit the incorporation and lead to acetabular cup loosening. At last, comparing to tantalum augments, RSC is much more cost-effective, and has the biological advantage of an autograft.

Nonetheless, there are some limitations to this study. First, the sample size is not large enough and the follow-up time is relatively short. Second, only 23 patients completed all of the scintigraphy exams after surgery, others only finished once or twice. Since these patients' results were relatively consistent with the rest, we did not exclude them from the analysis. Although the functional and radiological results were both excellent determined by experienced physicians and all the patients were satisfied as well, further prospective study and longer evaluation with different scoring systems may be needed to fully demonstrate the effectiveness of this technique.

In conclusion, in the short-term follow-up, the RSC technique for acetabular augmentation of hip dysplasia is reliable, cost-effective, and provides complete coverage for the cup and assuring proper stability. However, long-term follow-up is still needed.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

This project was supported by Bridging Fund 2021 University of Debrecen, Faculty of Medicine.

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