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ORIGINAL PAPER

Total hip replacement in developmental dysplasia using an oval-shaped cementless press-fit cup

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Abstract
Purpose Acetabular roof deficiency due to subluxation of the femoral head (Hartofilakidis type II) increases the complexity of total hip arthroplasty. In these cases some form of support is usually required, to reach stable fixation of the acetabular component. Pursuing this aim, the oval-shaped cementless cranial socket could be an alternative to conventional treatment options.
Methods Between 1998 and 2008, 37 patients (40 hips) underwent primary total hip arthroplasty using the cranial socket (mean follow-up 5.6 years, range 26 to 133 months). In a retrospective study we compared these clinical and radiological results with the results of a matched control group consisting of 35 patients (40 hips) treated with a standard cementless hemispherical cup in combination with bulk femoral autografting (mean follow-up 6.9 years, range 30 to 151 months).
Results There were no statistically significant differences in the HHS ($p = 0.205$) or the SF-36 ($p = 0.26$) between both groups. There was no prosthesis failure due to septic or aseptic loosening. Time of surgery was significantly shorter in the cranial socket group ($p < 0.001$). The acetabular component could be placed in the ideal rotational hip centre in 24 (60%) hips in the cranial socket group and 32 (80%) hips in the control group, respectively.
Conclusions Our study indicates, that the cranial socket can be an alternative treatment option for the reconstruction of acetabular deficiency in osteoarthritis secondary to developmental dysplasia.

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Introduction

Total hip arthroplasty is the procedure of choice for most patients with advanced, symptomatic osteoarthritis due to developmental dysplasia of the hip. However, in such cases arthroplasty is significantly more complex because of the associated anatomical abnormalities [1]. In low dislocated hips the femoral head lies on and deforms the superior margin of the acetabulum. These hips are classified as Hartofilakidis type II. In contrast to dysplastic hips with an acetabular segmental defect that is contained, this type of defect usually requires some form of support. This again increases complexity of surgery and may lead to poorer long-term results [2].

There are different surgical strategies to overcome these anatomical abnormalities, but most of them remain controversial. Biomechanically, the primary surgical objective is the reconstruction of the femoral offset and anatomical centre of rotation [3]. Irrespective of pelvic bone stock, the socket should be located as near as possible to the anatomical centre of rotation. Recent studies have shown

that a high hip centre is not recommended, because hip load increases when the cup is placed more proximally or laterally. This leads to increased wear rates and poorer survival rates of the acetabular component [4, 5]. Placement of standard-sized cups may leave part of the component unsupported by native bone. This lack of support increases the stresses at the bone–implant interface and thus the probability of mechanical failure. Especially in cases in which the host bone contact is below 80%, poor acetabular survival has to be expected [6–8].

These problems encouraged us to search for a specific implant that makes a biological cementless fixation possible and moreover provides the possibility of an eccentric placement of the femoral head to reconstruct the rotational hip centre. The so-called cranial socket (Orthodynamics, formerly ESKA implants, Lübeck, Germany) is a cranially extended oval metal-backed cup. Good long- and mid-term results have already been obtained by using this implant for the management of bone loss in revision arthroplasty [9].

This study was conducted to determine the outcome of cementless total hip arthroplasty performed with the cranial socket system in patients with osteoarthritis and acetabular roof deficiency secondary to developmental dysplasia of the hip. A retrospective cohort study was performed to compare the clinical and radiological results with the results after acetabular reconstruction by bulk femoral autografting and implantation of a hemispherical press-fit cup.

Materials and methods

Patient demographics

Patients with osteoarthritis and acetabular roof deficiency secondary to developmental dysplasia (Hartofilakidis type II) who had undergone primary total hip arthroplasty between 1998 and 2008 were identified from the unit's arthroplasty database. Patients were included in this study regardless of whether they had previous surgery. There were 37 patients treated by 40 primary total hip replacements using the cranial socket system (group I). We then searched the database to identify 40 primary total hip procedures using a hemispherical standard press-fit cup after reconstruction of the acetabular roof by bulk femoral autografting. These 35 patients were matched for age, gender and BMI and served as a matched control group (group II) (Table 1). The minimum follow-up for inclusion into one of the groups was 24 months (study group: mean 5.6 years, range 26–133 months; control group: mean 6.9, range 30–151 months). Institutional Review Board approval (no. 4013/11) was obtained before initiation of this study.

Table 1 Patient demographics

Parameter	Study group (I)	Control group (II)	*p*-value (test statistic)
Gender (male/female)	12/28	8/32	0.99[a]
Age (years), mean	53.1	52.3	0.78[b]
Height (cm), mean	166.1	163.8	0.35[b]
Body weight (kg), mean	70.9	68.9	0.38[c]
BMI (kg/m^2), mean	25.8	25.5	0.81[c]
Side (right/left)	20/20	21/19	0.20[a]
Preoperative HHS, mean	39.9	37.1	0.28[c]
Follow-up (years), mean	5.57	6.92	0.04[c]

BMI body mass index, *HHS* Harris hip score

[a] Chi-squared test

[b] *t*-test

[c] Mann–Whitney U test

Preoperative planning

The classification system according to Hartofilakidis [10] was used to assess the morphological type of developmental hip dysplasia. Until 2004 the acetabular cup size, position and inclination was preoperatively planned using acetate templating. Since then we have used digital planning software (mediCAD®, Hectec GmbH, Landshut, Germany). During the planning process, we first tried to position the acetabular template in the ideal anatomical centre of rotation [11] (Fig. 1). Then the proportion of the cup, which was expected to be not covered by host bone, was analysed. If this proportion exceeded 20%, we generally considered additional surgical reconstructive techniques, such as bulk femoral acetabular roof grafting (Fig. 2) or implantation of a

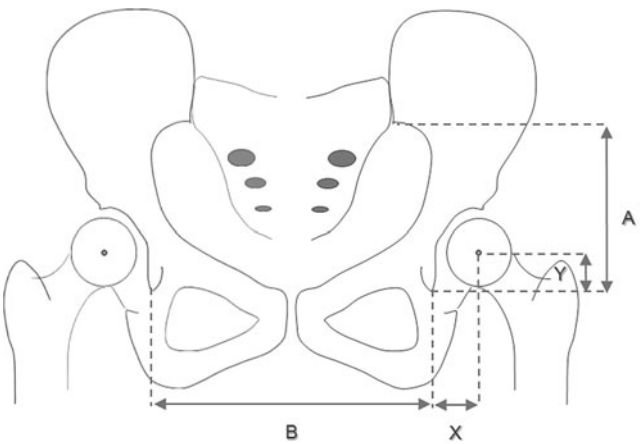

Fig. 1 Determination of the rotational hip centre using Pierchon's method: **A** is the vertical distance between the interteardrop line (**B**) and a line which joins the lower points of the sacroiliac joints. Two indices can be described to calculate the correct center of rotation: Y/A = 0.2 for men or 0.18 for women, X/B = 0.3 for men or 0.25 for women

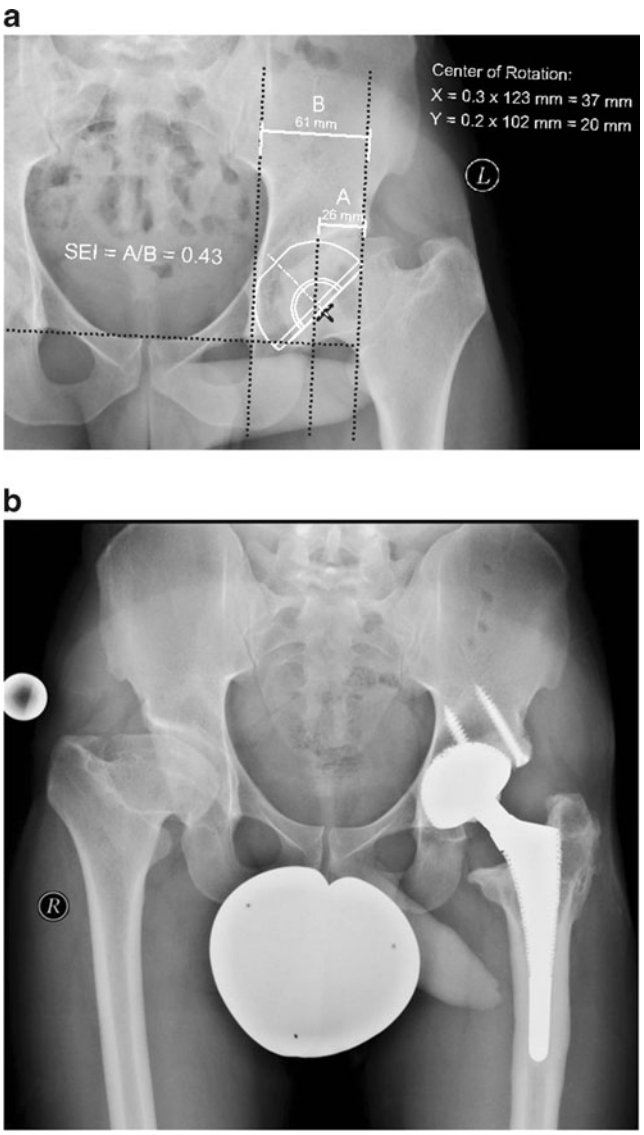

Fig. 2 Radiograph of a 38-year-old man. **a** Determination of the socket extrusion index (SEI). It describes the proportion of the cup, which is expected not to be covered by host bone after correct implantation. The SEI is calculated dividing the horizontal distance of the uncovered socket by the horizontal distance between the medial and lateral edge of the socket-template, which is positioned in an inclination angle of ideally 45 degrees. **b** Radiograph taken one-year postoperatively showing acetabular reconstruction by bulk femoral autografting

cranially extended cup. In these cases, we used a minimally-invasive anterolateral approach to the hip joint instead of the direct anterior approach for a better exposure of the antero-lateral acetabular roof and adjacent ilium.

Surgical technique and implant

All patients included in this study were operated upon by two experienced senior surgeons. The reamers were used in ascending series until the definitive cup size was achieved, which was determined by the anteroposterior diameter of the acetabulum. By placing the last reamer in the correct position, the true extent of the defect became apparent. If more than 20% of the reamer was uncovered by host bone, alternative reconstruction techniques were considered. In cases of acetabular grafting, we used hemispherical standard press-fit cups (Cup 2000, Orthodynamics, Lübeck, Germany). Apart from that, we used the cranial socket, which is available in six sizes with an outer diameter from 52–72 mm. The cranio-caudal is greater than the antero-posterior dimension while the cranial extension is on average 10% of the antero-posterior diameter (Fig. 3). The cup height increases with the cup diameter from 29 to 38 mm. Both cups are made of Cobalt-Chrome-Molybdenon alloy and coated with Titanium-Niobium. They have a porous coated surface structure with hexapodal forms (Spongiosa metal® II) with a porosity of approximately 70% and pore sizes from 200 to 2000 μm [12]. Cup inserts made of UHMWPE were used in all cases (ID 28, 32 and 36 mm). For heterotopic ossification prophylaxis we used cautery during surgery and postoperatively non-steroidal anti-inflammatory drugs were administered.

Follow-up evaluation

Apart from demographic data, history of previous surgery, pre- and postoperative range of motion, postoperative course (including revisions and complications) and surgery details (including duration of surgery) were analysed. For the purpose of internal quality management, functional outcome has been analysed by using the Harris hip score (HHS) preoperatively and at every clinical follow-up. Patient health related quality of life was assessed one-year postoperatively by the Medical Outcome Study Short-form 36 (SF-36). All these data had been prospectively collected in our arthroplasty database.

Radiographic analyses were independently performed by two of us. Therefore, the postsurgical and most recent (taken on average 2.3 years postoperatively) anteroposterior and axial radiographs were analysed using digital planning software. Radiographs taken before 2004 were scanned and digitalised. Magnification bias was corrected by calibration with the implanted prosthetic head. Radiographic failure of

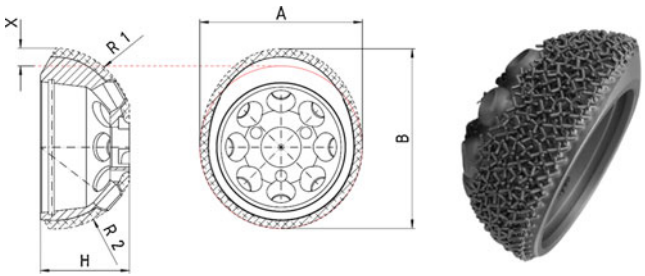

Fig. 3 Technical details of the cranial socket

the acetabular cup was defined if there was a continuous radiolucent line, a significant change in cup position (≥3 mm migration), progressive osteolysis, broken screws or a significant change of the cup inclination angle [13–16]. Any deviation greater than the accuracy of the measurement technique (which was determined to be two degrees) was defined as significant change of the inclination angle. The ideal centre of rotation was again determined using Pierchon's method [11]. Placement within five millimetres of the measured centre of rotation (five mm as an absolute distance from the ideal centre of rotation, ten mm rectangle around the centre) was determined as orderly positioning. Heterotopic ossifications were classified according to Brooker et al. Graft resorption was assessed by using the classification system of Gerber and Harris. Incorporation of the graft was considered if there were no radiolucent lines between graft and host bone or bridging trabeculae were visible.

Statistical analysis

We used the SigmaStat 3.5® software (systat) for all analyses. Values for continuous variables were reported as the mean, standard deviation and range. If the test statistic followed a normal distribution we used the Student's t-test to evaluate differences between two samples. For non-normally distributed data the Mann–Whitney U test was used. To compare the frequency of two characteristics we used the chi-squared test. A p-value of <0.05 was considered significant.

Results

The average HHS showed a significant improvement in both groups from preoperatively to the final follow-up ($p<0.001$). The mean postoperative HHS was 89.8 (SD 10.1, range 65–100) in the study group and 88.5 (SD 8.4, range 54–100) in the control group. There was no statistically significant difference between both groups ($p=0.205$). There was no statistically significant difference in the postoperative SF-36 subscales between both groups (Table 2).

During the follow-up period there was no implant failure due to septic or aseptic loosening. In the cranial socket group three complications were documented (7.5%). There was one patient with a temporary palsy of the peroneal nerve. In another patient an intraoperative periprosthetic femoral fracture required osteosynthesis with three cerclage wires. There was one dislocation (femoral head size 32 mm, 52° inclination angle, 25° anteversion) three weeks after operation, which was treated by closed reduction. In the control group, five patients had postoperative complications (12.5%). These included two superficial wound healing problems, a deep vein thrombosis and one case of haemorrhage, in which reoperation was necessary to control bleeding. One patient suffered from recurrent anterior dislocations. In this case, the acetabular component was revised three months after primary operation for an excessive anteversion and inclination angle (femoral head size 32 mm, 57° inclination angle, 48° anteversion). Intraoperatively, there was no stable interface between host bone and the bulk femoral autograft. Therefore, the component was changed to a cranial socket to cover the remaining antero-lateral defect.

With a mean time of 114.3 minutes (SD 19.1, range 80–159 minutes), duration of surgery was significantly ($p<0.001$) longer in the control group compared to the study group (mean 83.9 minutes, SD 9.7, range 62–109 minutes).

In accordance with the clinical symptoms, an analysis of the most recent radiographs revealed no signs of acetabular or femoral component loosening. There was no progressive osteolysis or implant failure as defined by broken screws, continuous radiolucent lines or significant change of the cup inclination angle. After correction for magnification bias the radiographic analysis did not indicate any notable horizontal or vertical migration. Periarticular ossifications were detected in four hips of the study group (10%; 3 grade I, 1 grade II) and six hips of the control group (15%; 3 grade I, 3 grade II). None of them suffered from pain or reduced range of motion.

The postoperative centre of rotation in the study group was positioned more laterally ($p<0.001$) and caudally ($p=0.001$) than in the control group (Fig. 4). The acetabular component could be placed in the ideal position (≤ 5 mm cranial/caudal or medial/lateral from the anatomical centre of rotation) in 24 (60%) hips in the study group and 32 (80%) in the control group, respectively. The acetabular inclination angle was significantly ($p>0.001$) higher in the study group (mean 49.9°, SD 5.2°, range 42–62°) than in the control group (mean 44.6°, SD 5.6°, range 35–57°).

Table 2 Postoperative mean SF-36 scores (standard deviation)

Group	PF	RP	BP	GH	VT	SF	RE	MH
Study group	67.4 (26.1)	75 (39.6)	77.9 (23.3)	67.4 (18.5)	60.4 (20.3)	79.9 (25.8)	83.3 (32.4)	74.1 (19)
Control group	57.1 (28.3)	66.2 (42.6)	70.9 (28.1)	61.1 (23.4)	55 (20.4)	77.7 (23.2)	65.8 (43.4)	68.6 (20.8)
p-value	0.09	0.31	0.4	0.23	0.21	0.51	0.06	0.25

PF physical function, *RP* role-physical, *BP* bodily pain, *GH* general health, *VT* vitality, *SF* social functioning, *RE* role-emotional, *MH* mental health

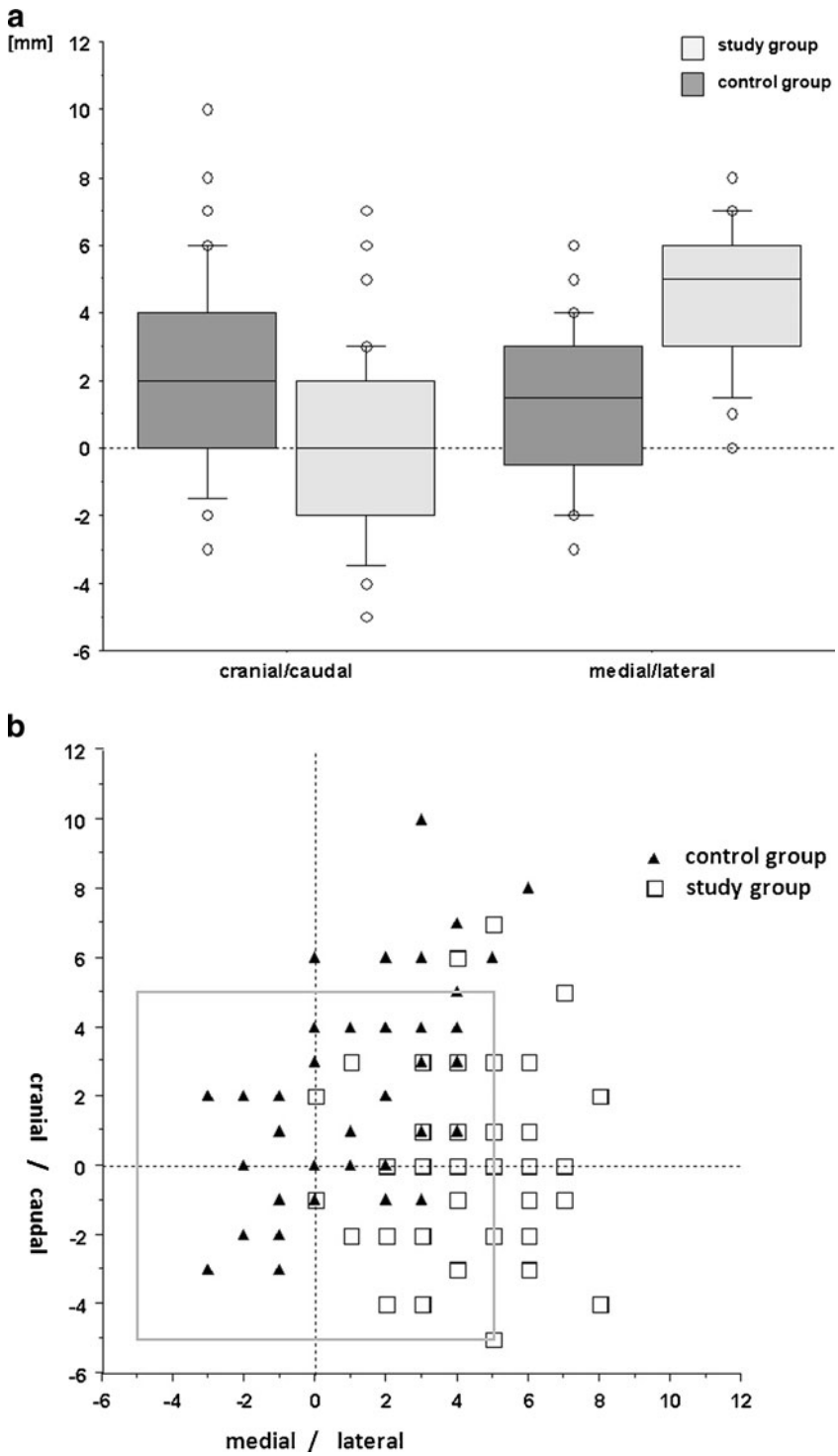

Fig. 4 Boxplot (**a**) and scattergram (**b**) showing that the centre of rotation in the study group was positioned significantly more laterally and caudally compared to the control group.

Regarding the control group, bridging trabeculae across the graft–host interface could be clearly identified in 35 hips (87.5%). In four hips the interface line between the grafted and the host iliac bone was still visible at the latest follow-up. In three hips the resorption of the graft was graded as minor, and in one case it was graded as moderate according to the Gerber and Harris classification system.

Discussion

If both sufficient coverage of the implant and restoration of the normal centre of rotation of the hip cannot be achieved by the placement of small standard acetabular implants, alternative reconstructive techniques have to be considered. With the medial protrusio-technique (cotyloplasty), the medial wall of the pelvis is reamed in a controlled way to reach

a sufficient containment of the acetabular component. Though joint reaction forces are reduced by this technique, a surgically produced protrusio of the pelvis is accepted. So far, there is only limited data confirming the safe use of this technique [17]. Another option for the reconstruction of this defect is the augmentation with bone cement alone. But without additional support this is associated with high acetabular loosening rates [18]. Acetabular reconstruction by bulk femoral autografting or bone impaction grafting has been described in a variety of ways and represents probably the gold standard at the time [19–22]. Some surgeons have abandoned the use of bulk autografts especially in older patients, because of the increased operative time, need for more soft tissue exposure and concerns for graft resorption [23]. Postoperatively the rehabilitation process can be protracted, because partial weight-bearing is required. To overcome these disadvantages, some authors recommend the use of small cemented polyethylene cups that have an oblong shape with the supero-inferior dimension greater than the antero-posterior. The cavity of the femoral head is placed eccentrically, thus providing greater polyethylene thickness superiorly, in spite of the small external diameter. Therefore, the centre of rotation can be located more distally. While many surgical techniques have been described to overcome the problems associated with acetabular deficiency, many remain controversial and some actually lead to poor prosthetic long-term survival rates, especially in younger patients [24, 25].

In our study, the use of the cranial socket led to good mid-term results, comparable to those which can be obtained by using bulk femoral autografting in combination with hemispherical standard cups. During the follow-up period there was no implant failure due to septic or aseptic loosening. There were no statistically significant differences in HHS or SF-36 between both groups. Time of surgery was significantly shorter in the cranial socket group. Thus, implantation of the cranial socket is a time-saving procedure, which furthermore provides instant primary stability. Therefore, the cranial socket can be an alternative treatment option in acetabular deficiency. One may speculate that especially biologically older patients with a high rate of comorbidities may benefit from immediately postoperative weight-bearing and a shortened surgery time, as these patients are prone to secondary complications after total hip arthroplasty.

The special oval implant shape enables a reconstruction of the anatomical centre of rotation (Fig. 5). Nevertheless, bone grafting in combination with a hemispherical standard cup can reconstruct the anatomical centre of rotation in a more accurate way than using the cranial socket system, as it is shown by our study. According to the model of Bicanic et al. placement of the acetabular cup within five mm of the ideal anatomical centre of rotation does not change hip load

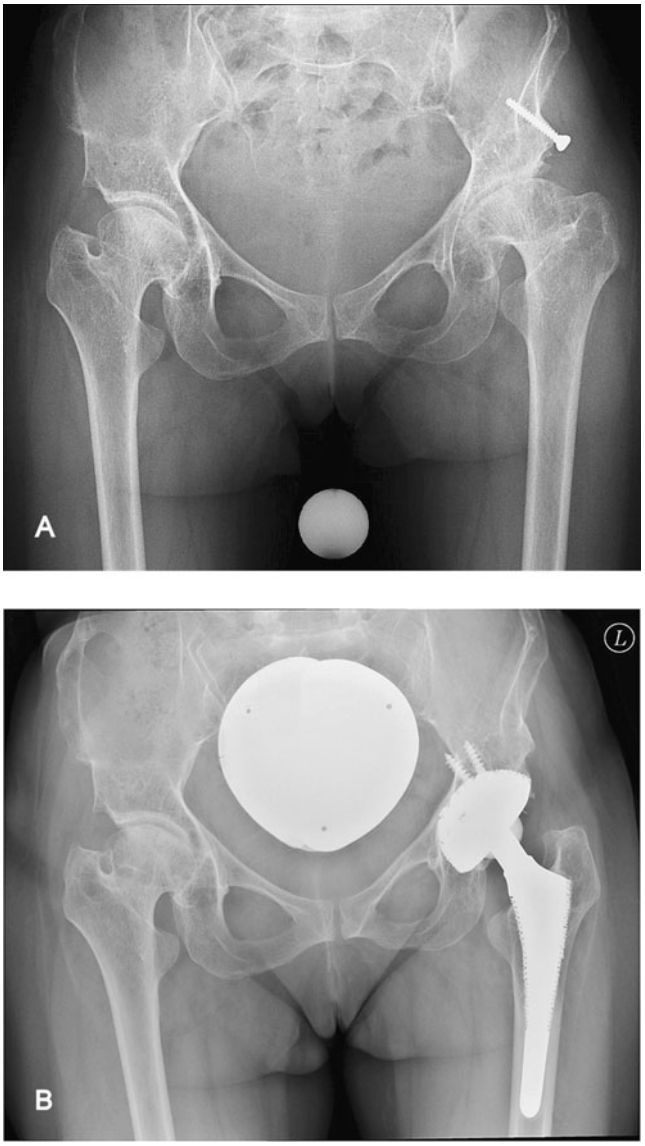

Fig. 5 Radiographs of a 51-year-old woman. **a** Preoperative radiograph showing a Hartofilakidis type II dysplastic left hip with acetabular roof deficiency and cranialisation of the rotational hip centre. About 40% of a standard hemispherical acetabular component would remain uncovered by host bone. **b** Radiograph taken two years postoperatively showing reconstruction of the anatomical hip centre of rotation and a stable cranial socket

over 10% relative to the hip load in the ideal centre of rotation [4]. When determining placement within 5 mm of the radiological measured centre as orderly positioning, the acetabular component could be placed in the ideal position in 60% of the hips in the study group and 80% in the control group. Because a significant deviation from the ideal centre of rotation can lead to increased wear rates and poorer survival rates of the acetabular component, long-term outcome in our patients would be of special interest.

One could speculate that the more lateral and caudal position of the anatomical centre of rotation in the study

group presumably results from the insufficient size scale of the cranial socket, which initially was designed as a revision implant. This effect may also contribute to the significantly higher inclination angle found in the cranial socket group. For widespread application of the system, it would therefore be necessary to design smaller cup sizes. Moreover, in biologically younger, active and healthy patients we still recommend the augmentation of the antero-lateral acetabular defect by bulk femoral autografting in order to reduce the size of the defect and to create sufficient autochthonous bone stock for possible future revisions. Using the cranial socket in primary hip arthroplasty, one should bear in mind that in the event of loosening, the bone deficiency might be quite large [9].

In conclusion, for patients with acetabular roof deficiency in developmental dysplasia, the use of the cranial socket can be an alternative option for the reconstruction of the acetabulum in total hip arthroplasty. In this study, good mid-term results were obtained, but long-term outcome has to be the subject of further investigation.

Conflict of interest statement The authors declare that they have no conflict of interest.

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