ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Cementless hip arthroplasty and transverse shortening femoral osteotomy with the S-ROM stem for Crowe type IV developmental dysplasia

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Abstract

Introduction The aim of this study has been to present outcomes after cementless arthroplasty for developmental dysplasia Crowe type IV of the hip, with transverse subtrochanteric shortening osteotomy and using the S-ROM stem.

Methods We evaluated radiographs, functional scores and complications in a consecutive series of 23 patients (28 hips) with high dislocation of the hip. The average age of patients at surgery was 49.9 (range 22–68) years. The operations were performed between 2007 and 2013. Patients were assessed retrospectively–clinically and radiographically during the year 2018.

Results The mean follow-up period was 94 (range 60–134) months. The average Harris hip score improved from 39.9 to 84.0. The mean leg length discrepancy decreased from 5 cm preoperatively to 1.4 cm at the final follow-up. All acetabular components were implanted into the true acetabulum, and all prostheses were stable at the latest examination. No neurovascular damage was recorded. We have identified specific complications in seven hips (25%) in total: Intraoperative femoral fracture required fixation in four hips; three hips (10.7%) needed revision: Recurrent dislocation, with the need for cup reorientation, occurred in two hips (in one of them, this was followed by the subsequent need for resection of heterotopic ossification); there was one aseptic stem loosening with the need of one-stage revision. All the osteotomies healed within 8 months.

Conclusion Hip arthroplasty with transverse shortening femoral osteotomy, using S-ROM stem, is an acceptable, but not complication-free treatment method in patients with Crowe type IV developmental hip dysplasia, in the midterm.

Keywords Hip dysplasia · Shortening femoral osteotomy · S-ROM stem

Introduction

Total hip arthroplasty (THA) in patients with Crowe type IV developmental dysplasia of the hip (DDH) is a technically more demanding procedure and has a higher complication rate than surgery in primary coxarthrosis [1]. Anatomical abnormalities typically associated with high hip dislocation are: a deformed femoral head, a short femoral neck with excessive anteversion, a narrow femoral medullary canal, a hypoplastic true acetabulum with reduced depth and deficient superior bone stock, a posteriorly located greater trochanter and muscular contractures [2, 3]. The optimal surgical treatment for such patients remains controversial. Most studies recommend that the center of rotation should be at the level of the true acetabulum because of the reduced contact stress and a lower failure rate of cups [4–7]. The femur should be shortened in order to reduce the hip more easily and to avoid excessive limb lengthening with possible

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sciatic nerve stretching [1, 4–8]. Shortening osteotomy has been described at different anatomical levels: subtrochanteric, the mid-shaft and distally in supracondylar area [9–11]. Recently, increasing attention has been focused on subtrochanteric osteotomy performed by different surgical techniques: Z-shaped, double-chevron, transverse or oblique [5, 8, 11–13]. Each of these techniques has its merits and disadvantages. There are few cementless stems used in these techniques [5, 6, 8, 14–19]. The S-ROM prosthesis is a treatment option in patients with DDH due to its versatility [6, 15, 18]. The aim of this study was to evaluate outcomes after implantation of THA for Crowe type IV DDH, using the S-ROM modular stem, combined with shortening transverse subtrochanteric osteotomy. Our hypothesis was that this technique is likely to lead to satisfactory results in the midterm.

Materials and methods

This is a retrospective cohort study. Patients' records were reviewed retrospectively for demographic data, details of the operation, X-rays and follow-up results.

Patients and perioperative management

The study group consisted of 23 patients with symptomatic Crowe type IV developmental dysplasia of the hip who underwent cementless THA using the S-ROM stem, combined with shortening, transverse, subtrochanteric femoral osteotomy, between 2007 and 2013. Included in this study were 28 hips in 23 patients—4 males and 19 females (mean age 49.9, range 22–68 years; mean body mass index 26.2 kg/m^2, range 21.2–29.6)—who could be followed up for a minimum of 5 years. All patients gave informed consent for inclusion. This study conforms to the Declaration of Helsinki and was authorized by the ethical committee of the first author's institution. Five patients (all females) underwent bilateral sequential THA (in the period from 4 to 18 months after the first THA).

The inclusion criteria were: severe pain (unresponsive to nonoperative management); considerable difficulty in walking and functional impairment while performing daily activities and low quality of life; DDH type IV of Crowe's classification [20]; each patient's own informed decision to accept the surgery; complete clinical and radiological follow-up of a minimum of 60 months. The exclusion criteria were: asymptomatic high hip subluxations; previously operated hips (osteotomy, trauma, etc.); inflammatory or oncologic diseases in the area of operated hip joint; neuromuscular compromise in the symptomatic extremity; and incomplete follow-up.

Fig. 1 Anteroposterior radiograph of a 39-year-old female before surgery. Developmental dysplasia of the right hip joint Crowe type IV

Table 1 Clinical and radiological parameters

Indicator	Preoperative	Postoperative
Harris hip score		
Mean (points)	39.9	84.0
Rating (number of hips)		
Excellent (90–100 points)	0	3
Good (80–89 points)	0	23
Fair (70–79 points)	0	2
Poor (≤70 points)	28	0
Limping (number of hips)		
Severe	15	0
Moderate	8	1
Slight	5	4
None	0	23
Trendelenburg sign (number of hips)		
Positive	28	1
Negative	0	27
Dorr classification (number of hips)		
Type A	7	
Type B	11	
Type C	10	

All included patients were evaluated preoperatively by use of the Harris hip score (HHS) and Merle d'Aubigné and Postel hip score (MAP) [21]. Abductor function was assessed according to Trendelenburg sign. The patients were assessed preoperatively by standard anteroposterior (Fig. 1) and lateral radiographs of the pelvis and hip. The femoral morphology and bone quality were classified according to Dorr et al. [22] (Table 1). Parameters of the true acetabulum

(location, depth, size, anteversion, anterior and posterior border bone defects) were identified from the CT 3-D scans (Siemens, Germany). Preoperative planning and templating on radiographs were used to determine the implant size (cup and stem) and the length of femoral resection needed, taking into account any lengthening due to distal transfer of the rotation center. A femoral template was placed with the prosthetic femoral head center at the height of the tip of greater trochanter (to preserve bone stock, optimize the abductor moment arm and avoid osseous impingement). The vertical difference between the center of the prosthetic femoral head and the center of the cup shows the maximal amount of lengthening without femoral shortening. The osteotomy was planned in height at 1–2 cm below the end of the proximal sleeve, corresponding to 1–2 cm beneath the lesser trochanter. We planned the amount of femoral shortening so that the lower limb would be lengthened no more than 3–4 cm.

Leg length measurements were performed at clinical examination, where the difference in the distances between the anterior superior iliac spine and the medial malleolus of each leg represented the limb length discrepancy (LLD).

Surgical procedures

Surgery was performed under general, or spinal, anesthesia with the patient placed in a supine position. The operations were carried out by two senior surgeons (L.N. and B.S.). The transgluteal approach was used in each case. The hypertrophic and elongated joint capsule was resected; the fatty tissue filling true acetabulum was identified. After neck resection (using an *L*-shaped osteotomy appropriate for the S-ROM sleeve, approximately 1 cm proximal to the lesser trochanter), the true acetabulum was prepared. The obturator foramen and the residual pulvinar served as landmarks. The true acetabulum was always small and showed trophic changes due to lack of joint function. As acetabular walls are fragile, we used hemispherical reamers to obtain an interference fit between the anterior and posterior columns. We reamed until almost 80% coverage of the cup (evaluated by the surgeon) was achieved, in almost all analyzed cases as far as medial wall of the true acetabulum. We used reverse reaming (impacting) with bone grafting (from resected femoral head) until the coverage of the cup seemed to be satisfactory. The acetabulum was under reamed by 1–2 mm. The cup was then implanted in the position of the anatomical hip center (40°–45° of inclination and 15° of anteversion) by a press-fit technique. A Pinnacle cementless hemispherical press-fit cup (DePuy, Warsaw, IN, USA) (range 38–52 mm) was inserted into the true acetabulum in every case. The mean diameter was 44 mm. Additional screws were used in four cases to achieve primary stability of the shell (the usage of the screws depended on the surgeon's intraoperative

decision). A conventional ultra-high molecular weight polyethylene liner was used in nine hips, and a ceramic liner was used in each of the other hips. We did not implant constrained liners.

After the acetabular component implantation, the femur was externally rotated 90° and the femoral canal prepared, using the dedicated reamer for the S-ROM stem. We reamed the femoral canal until the filling distally was of 90–100% (evaluated with the use of X-ray intraoperatively), thereby determining the final distal diameter of the stem. Femoral preparation was performed before the osteotomy. Conical and triangular reaming of the metaphysis was then performed to prepare the metaphyseal cone. Subtrochanteric femoral shortening osteotomy was performed, in accordance with the preoperative templates, by resection of a length of the femur below the lesser trochanter (Figs. 2a–c and 3). The length of the removed bone stock ranged from 2 to 8 cm. After trial stem insertion, the reduction was performed. If the trial reduction was impossible, additional bone was incrementally resected at the osteotomy site until reduction was achieved. The stem was inserted with an initial anteversion of 15°–20°; in the cases of unstable hips, the anteversion was corrected individually, according to the surgeon's decision.

We evaluated the approximate LLD preoperatively observing the malleolar levels (assessed manually by the surgeon). When the trial reduction, stability and leg length were appropriate, the final component was implanted. After implantation of the proximal sleeve, the stem was inserted with appropriate anteversion. The femoral fragments were held with forceps during stem insertion to control the rotational alignment. Any gaps at the osteotomy site were filled with autogenous cancellous bone. Cerclage wire protection at the osteotomy site was performed in the initial five cases and thereafter only in cases with poor bone quality or intraoperative femoral fracture. In the case of intraoperative fracture of the femur, a titanium band was used to secure the osteotomy. In this study, we used the primary S-ROM femoral components (DePuy, Warsaw, IN, USA), made of titanium alloy with a stem diameter of 9–15 mm. The mean diameter was of 13 mm. Six hips were treated with 22-mm cobalt–chromium femoral heads, and we used 28-mm ceramic heads in 15 hips, 28-mm cobalt–chromium heads in three hips and 36-mm ceramic heads in four hips.

Postoperative management

Wound drainage was removed and both active and passive movements started, on the first postoperative day. Patients were discharged from 9 days postoperatively (range 7–12). Walking touch weight-bearing with crutches was recommended until 6 weeks postoperatively, when patients were examined clinically and radiologically; thereafter, partial
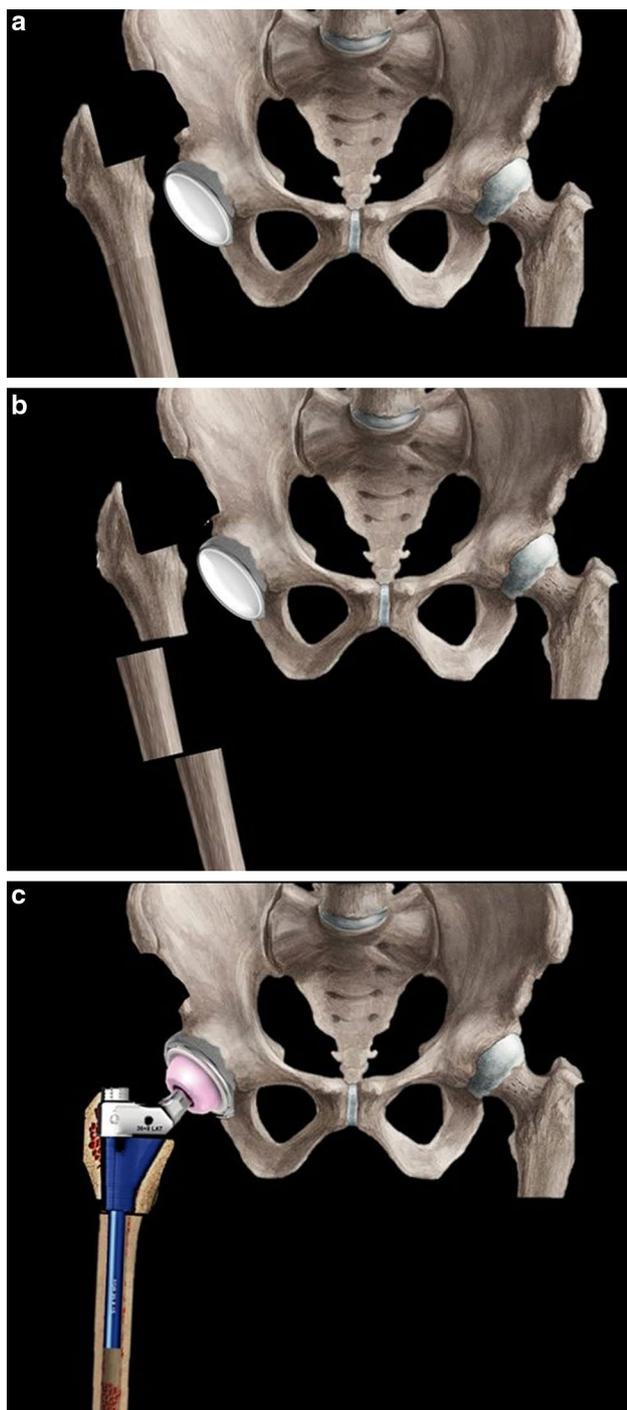
Fig. 3 Anteroposterior radiograph of the same patient as Fig. 1 (39-year-old female); first postoperative day after the cementless THA of the right hip joint (Pinnacle cup, S-ROM stem). The osteotomy line in the subtrochanteric area is visible. The shortening of the femur was 5 cm

Patients were then examined, with X-ray, every 2–3 months until the end of the first postoperative year and thereafter once yearly until an average follow-up of 94 months.

Outcome measures

We recorded intraoperative complications (neurovascular damage, intraoperative femoral fracture), both early and late postoperative complications (dislocation, infection, femoral osteotomy nonunion, heterotopic ossification with clinical manifestation) and the need for the reoperation. The radiographs (anteroposterior and lateral) were examined by a blinded senior and experienced orthopedic radiologist. The time to healing of the osteotomy was assessed according to the following radiological criteria: callus formation at the osteotomy site, restoration of continuity of the cortical bone and gradual disappearance of radiolucent lines between the femoral fragments (Fig. 4).

At the final follow-up visit (Fig. 5), we examined all hips for the implant position and for the presence of osteolysis and wear, using the Gruen et al. method for the femur and De Lee and Charnley method for the acetabulum [23, 24].

Clinical examination at the final visit included: LLD, assessment of abductor strength, with the use of Trendelenburg test, HHS, improvement in overall limp (according to HHS), MAP, patient's subjective satisfaction with the final result and with their original decision to undergo this procedure. The clinical and radiological evaluations were performed by one surgeon (M.H.), who did not perform any of the surgical procedures.

Fig. 2 **a** Illustration after the femoral neck resection (for the S-ROM stem) with implanted cup, **b** transverse shortening femoral osteotomy with femoral fragment removal, **c** illustration after the S-ROM stem implantation and reduction in the hip

weight-bearing was permitted. After the next clinical and radiological examination at the third month, full weight-bearing was allowed. The use of crutches was abandoned at around the 6th postoperative month, on an individual basis.

Fig. 4 **a** Anteroposterior radiograph of the same patient 4 months after surgery. The position of the prosthesis is correct, and the osteotomy has healed. **b** Axial radiograph of the same patient showing the correct stem diameter and position. The osteotomy has healed
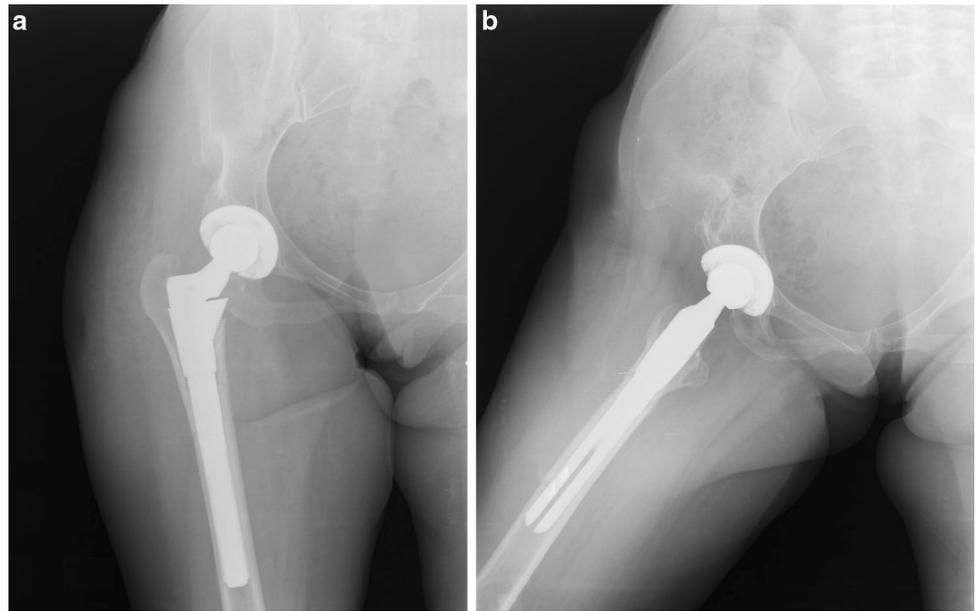

Fig. 5 Anteroposterior radiograph of the same patient 5 years after surgery. The position of the prosthesis is correct without the loosening

Statistical analysis

Two-sided, paired Student's *t* test was used for statistical analysis of the pre- and postoperative HHSs, MAPs and LLDs. Statistical differences were considered to be significant when the *p* value was < 0.05.

Relatively large effects (under guidelines from Cohen, 1988) were reported in the previous studies for HHSs, MAPs and LLDs after shortening osteotomies [1, 5, 6, 8, 11, 25]. A power analysis using the R 3.5.0 (R Core Team, 2018), the power package, indicated that a total sample of 15 hips would be needed to detect large effects ($d = 0.8$) with 80% power using a two-sided paired *t* test between means with alpha at 0.05.

Results

Functional outcomes

All 23 patients were followed, and the final evaluation was performed at a mean of 94 months (range 60–134). The mean HHS improved from 39.9 (range 23–59) points preoperatively to 84.0 (range 74–96) points at the final follow-up. The mean MAP improved from 8 (range 3–12) points preoperatively to 16 (range 12–17) points at the final follow-up.

The final HHS and MAP were significantly higher than preoperatively ($p = 0.001$). The Trendelenburg sign was positive in all hips preoperatively. One hip in one patient with unilateral arthroplasty (3.6%) had a positive postoperative Trendelenburg sign that caused moderate limping at the final follow-up. Twenty-two patients had a negative postoperative Trendelenburg sign (Table 1). The mean LLD in the 18 patients with unilateral dysplasia was 5 cm (range 1–10) preoperatively, whereas five patients with bilateral high hip luxation had no LLD before the first THA, and it was 1.4 cm (range 1–5) across the whole cohort at final follow-up.

The LLD was significantly lower postoperatively ($p = 0.001$). The mean femoral shortening was 4.6 cm (range 2–8).

The functionals scores and LLD improved significantly.

Restoration of the anatomical hip center was achieved in all hips by placing the acetabular component into the true acetabulum. All 28 osteotomies united without complications. The mean healing time was 4.7 months (range 3–8).

Complications and revisions

We recorded intraoperative fractures of distal femoral fragments in four hips (14.3%), and they were treated with titanium band cerclages. All these four hips were without any complications at further follow-up. Three hips (10.7%) were revised during the postoperative period.

Due to dislocation attributable to cup loosening and valgus malposition, the first hip (unilateral) was revised 1 week after surgery by reorientation of the cup with additional screw fixation. In this hip, Brooker type III heterotopic ossification occurred during the following 6 months, with limitation of motion. One and half years after the first revision, a second procedure was performed—to remove the ectopic bone—but it recurred. Infection was not diagnosed. At the last visit—9 years after the primary implantation—the prosthesis was without signs of loosening, but still with ectopic ossification and pain-free limited motion.

Another hip (unilateral) was revised for aseptic stem loosening (in Gruen zones 1–6), 2 years postoperatively, by one-stage stem revision (with a larger S-ROM stem). No infection was detected. At the last visit (6 years after the revision), the prosthesis shows osteolysis up to 1 mm in Gruen zone 3–4, but the patient is asymptomatic and able to walk fully weight-bearing without crutches.

A third hip (right side of a bilateral implantation) was revised for the recurrent dislocation due to cup malposition and loosening. The first revision (cup reimplantation) was performed 3 years after the primary implantation. The dislocations recurred, and 13 months after the first revision, the patient required a further procedure (cup reorientation), but the instability recurred. After a further year, complete revision, with cup and stem replacement and reorientation, was performed. Four years after the last revision, the patient has mild pain during walking, but the prosthesis is stable without any osteolysis or ectopic ossification.

The last X-rays of another hip, at 7 years after the surgery, revealed Brooker type II ectopic ossification, despite the patient's being clinically asymptomatic. Another asymptomatic hip exhibited osteolysis up to 1 mm under the whole cup, 9 years after the surgery.

Heterotopic ossification was diagnosed in two hips (7.1%) in total. Osteolysis was diagnosed in two hips (7.1%) (one cup and one stem). No neurological complication was detected in our cohort. Deep venous thrombosis occurred in one patient and was treated successfully with the oral anticoagulants.

Only one patient (after a third hip revision) remains dissatisfied, and she says that she would not undergo this procedure again.

Discussion

Surgical treatment for high DDH (Crowe Type IV) is a challenge for cementless THA in adults, due to the pathological anatomy of the hip. Insertion of the cup into the true acetabulum requires a femoral shortening osteotomy in most of the cases [1, 8]. This type of arthroplasty is technically more demanding, and the complication rate is higher than for standard primary THA [5, 11]. The most frequent complications in Zagra's published series are: intraoperative femoral fracture, dislocation, delayed union or nonunion of the osteotomy site, neurovascular injury and implant failure [8]. Various techniques of femoral osteotomy and the choice of implants have been discussed in the literature [5–15]. This study retrospectively reviews the functional scores and complication rates in a series of patients with Crowe type IV hips reconstructed using an S-ROM stem and transverse shortening femoral osteotomy. This stem was used with satisfactory outcomes [11, 16, 17]. Preoperative clinical and radiological assessment with weight-bearing radiographs is essential for treatment decision-making. Insertion of the cup into the cancellous bone provides some mechanical strength in the acetabulum, and a good cortical rim fit of the cup component should be achieved. Over-reaming of the anterior and medial walls, as possible reason for cup loosening or malposition which can lead to THA luxation, should be avoided. We used only un-cemented porous-coated acetabular components, without the need to use autologous bulk grafting. Four cups required additional screw fixation. After inserting the cup, there would be likely to be, without femoral shortening, a high dislocation rate, excessive femoral anteversion and sciatic nerve traction. All of these problems may be solved by a subtrochanteric shortening osteotomy, which was transverse in our study. The instability of this technique, which may lead to delayed union or nonunion, is well described [3, 8]. One way, to increase the rotational stability of the osteotomy is some form of extramedullary fixation (cables, plates or allografts). The second choice is to use the S-ROM stem, functioning as an intramedullary fixation of the osteotomy. The advantage of this stem, combined with a transverse osteotomy, is the possibility to correct the excessive anteversion of the proximal femur. The small-diameter straight femoral stem is applicable for small and straight femoral medullary cavities in patients with DDH. Mismatch between proximal and distal intramedullary canal diameters, after the

Table 2 Previously reported results of THA with S-ROM stem and subtrochanteric shortening in the treatment of Crowe type IV DDH

Study	Number of hips evaluated	Mean follow-up (in months)	Technique of shortening femoral osteotomy	Mean HHS preoperatively/postoperatively	Revised hips in total (%) (reason for revision)
Bruce et al. [28]	9	56	Subtrochanteric transverse	HHS 31.0/81.0	2 (22.2%)—1 (hip instability) and 1 (femoral shaft fracture)
Onodera et al. [29]	14	61	Subtrochanteric transverse	HHS 38.0/82.0	1 (7.1%)—1 (nonunion)
Park et al. [30]	24	56	Subtrochanteric transverse	HHS 35.6/81.7	4 (16.7%)—3 (nonunion one with stem loosening) and 1 (cup migration)
Li et al. [6]	21	49	Subtrochanteric oblique/transverse	HHS 30.6/91.2	0
Present study	28	94	Subtrochanteric transverse	HHS 39.9/84.0	3 (10.7%)—2 (hip instability) and 1 (aseptic stem loosening)

osteotomy and removal of the fragment, may lead to problems with secure fixation and to nonunion. In this situation, the S-ROM stem offers the ability to provide rotational stability and compression of the osteotomy fragments with a proximal sleeve, and distal flutes and fins in both femoral fragments [6, 8]. Hua et al. described 24 hips after transverse shortening femoral osteotomy with cemented and cementless implants and osteotomy sites treated by bone grafting and cable fixation. Their mean follow-up was of 42 months, and the femoral shortening ranged from 10 to 45 mm. The HHS improved from 47.5 to 88.5. They recorded intraoperative femoral fractures in three hips and sciatic nerve palsy in one [26]. Our results are similar, but with a longer follow-up period. Three of our perioperative femoral fractures occurred in first half of the group of patients, and in our opinion, these happened due relative inexperience with the technique in the early cases. We have seen neither perioperative fracture of the proximal fragment nor problems with its rotational stability. A prophylactic cerclage wire protection should be placed on the distal femoral segment before the S-ROM stem insertion to prevent intraoperative femoral fractures.

Çatma et al. evaluated a total of 78 hips with Crowe type IV DDH using two fixation techniques of the transverse shortening femoral osteotomy with cementless monoblock stems, supplemented with either additional cable fixation or plate and screws. They observed no significant differences between the two groups. Final HHSs were 82.8 and 80.8, respectively [27]. Tözün et al. evaluated 66 hips with a mean follow-up of 90 months after the use of a step-cut femoral shortening osteotomy for high hip luxations. They used monoblock cementless stems. Twenty-one hips had had previously valgus osteotomies. The mean HHS increased from 49.0 to 86.0. Thirteen hips (19.7%) were revised during the follow-up period. Dislocation occurred in three cases, infection in four hips and, in one case, sciatic nerve palsy with femoral vein injury. Nonunion was observed in three cases [14]. Mutlu et al. [15] found a higher incidence of

osteotomy complications with the Zweymüller stems. There are few studies of the use of the S-ROM stem, but their results are comparable with ours (Table 2) [6, 28–30]. The largest published series was of 76 hips with a follow-up of 10 years, but they used additional osteotomy fixation—with an autogenous cortical bone plate with two wires. They have the lowest revision rate, but relative small lengths of femoral shortening. The overall incidence of complications was 14.5%. The mean HHS/MAP improved from 38.8/6.7 to 86.1/15.9 [16]. Zeng et al. analyzed 52 hips with a follow-up of 10 years. They used additional autograft with cerclage wires at the osteotomy site. They recorded no revision. The mean HHS improved from 33.7 to 89.8 [11].

The average length of femoral shortening was of 4.6 cm in our study. Hua et al. described an average shortening of 2.5 cm; Wang et al. 2.7 cm, Zeng et al. 3.5 cm; Li et al. 3.9 cm; Ollivier et al. 4 cm; and Sofu et al. 4.7 cm [1, 6, 7, 11, 16, 26].

When we compare the complication rate with similar groups of patients following other osteotomy techniques and implants, the S-ROM stem has comparable results in the midterm [5–7, 26].

The possible disadvantages of the modular femoral component are: corrosion problems because of excessive stress in the modular junction, risk of fracture and femoral osteolysis associated with fretting debris from the sleeve–stem junction. When we revised a loosened stem, we saw no metallic debris or blackening of the periprosthetic tissues intraoperatively.

The strength of our study lies in the length of follow-up (up to 134 months), using the same surgical technique with one type of osteotomy, one type of modular cementless stem and the fact that no patient was lost to follow-up. However, weaknesses included the limited patient numbers due to the relative rarity of this type of surgery and the fact that this study is a retrospective evaluation of prospectively followed patients without a control group.

Conclusion

Our study shows that transverse shortening subtrochanteric femoral osteotomy, fixed with the use of the S-ROM stem (without additional stabilization except titanium bands) during cementless total hip arthroplasty for Crowe Type IV DDH, resulted in satisfactory outcomes in the midterm. The survival rate is almost 90% over an average of almost 8 years. Evident improvement in clinical function with restoration of a more normal limb length, without neurological complications, was observed. Further long-term follow-up of a larger group of patients would help to establish the apparent benefits of this procedure.

Compliance with ethical standards

Conflict of interest The authors state that there are no conflicts of interest regarding the publication of this article.

Human and animal rights Every institution involved in this work has approved the human protocol for this investigation.

Informed consent Informed consent was obtained from the participants, and all investigations were conducted in conformity with ethical principles.

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