



Dual offset metaphyseal-filling stems in primary total hip arthroplasty in dysplastic hips after a minimum follow-up of ten years

Goksel Dikmen¹ · Vahit Emre Ozden¹ · Burak Beksac² · Ismail Remzi Tozun¹

Received: 6 March 2018 / Accepted: 12 September 2018 / Published online: 19 September 2018
© SICOT aisbl 2018

Abstract

Purpose The aim of this study was to assess the long-term performance of tapered one-third proximally coated stems in dysplastic hips.

Methods This study included 135 dysplasia patients (150 hips) who underwent a total hip arthroplasty and had a minimum follow-up of ten years. Single design tapered stems were used in all patients. There were 112 women (83%) and 23 men (17%) with a mean age of 45 years (23 to 72) at the time of surgery. The mean follow-up was 14.7 years (10 to 16.8). For clinical evaluation, the Harris Hip Score and Merle D'Aubigne scale were used pre-operatively and at the final follow-up. Implant survival was calculated using Kaplan-Meier survivorship analysis, with failure defined as a component revision for any reason.

Results Overall, one stem was revised for a deep infection. There were no other femoral stem revisions secondary to loosening, wear, periprosthetic fracture, or instability. Radiographic evaluation showed excellent stem osteointegration in all cases. Kaplan-Meier survivorship, with stem revision for any reason as the end point, was 98% at 14 years (95% confidence interval 92.5 to 99.8).

Conclusion This study demonstrates that a dual offset tapered stem achieved excellent survivorship and stability, as well as good clinical outcome scores with minimal thigh pain and stress shielding in patients with arthritis and developmental dysplasia of the hip; a dual offset tapered stem may be a suitable option for primary total hip arthroplasty in this group.

Keywords Tapered stem · Dysplasia · Primary total hip arthroplasty · Long-term outcome

Introduction

Cementless femoral component usage has increased over the last two decades [1]; wear and implant loosening are the main problems that affect the longevity of the cementless total hip

arthroplasty (THA) technique [2, 3]. Long-term clinical and radiographic results of cementless stem fixation have been favourable [1, 4–6]; however, number of factors influence initial stability and primary fixation. These factors include stem coating, implant geometric shape, bone quality, preparation technique, fixation level (diaphyseal and/or metaphyseal), and load transfer patterns [1, 7, 8]. The Synergy stem (Smith and Nephew, Memphis, TN) is an example of a proximally coated, tapered stem that features three-point fixation for initial stability, with reduced stress shielding and thigh pain seen with distal femur-fitting fully porous coated stems [1, 9]. Mid-term results of Synergy stem showed a 99.5% survivorship, without any severe stress shielding and loosening [4]. However, Nishino et al. in their report on 50 hips stated that severe stress shielding without loosening was observed in half of their cases at the ten to 12 year follow-up [5]. In addition, previously reported mid-term to long-term results of 94 hips in 84 patients demonstrated excellent implant survivorship (98.9% at 15 years) and functional scores without excessive stress shielding in a mostly osteoarthritic patient group [10].

✉ Goksel Dikmen
gdkmen@yahoo.com; goksel.dikmen@acibadem.edu.tr

Vahit Emre Ozden
vahitemre@gmail.com

Burak Beksac
bbeksac@gmail.com

Ismail Remzi Tozun
rtozun@gmail.com

¹ Acibadem Mehmet Ali Aydinlar University, Faculty of Medicine, Department of Orthopedics and Traumatology, Acibadem Maslak Hospital, Buyukdere Cad No 40 34457, Maslak, Istanbul, Turkey

² Department of Orthopedics and Traumatology, Acibadem Maslak Hospital, Buyukdere Cad No 40 34457, Maslak, Istanbul, Turkey

Primary total hip arthroplasty for osteoarthritis secondary to developmental dysplasia of the hip (DDH) is technically difficult because of anatomic abnormalities in these patients [11]. The femur in DDH patients has a shorter, valgus neck, a small and straight canal, and a higher degree of anteversion compared with normal femurs [12, 13]. Femoral canals are often wider in the anteroposterior than medial-lateral dimension in DDH. These anatomic differences in dysplastic femurs make stem placement harder, predisposing to malalignment and/or peri-operative fracture [14–16].

The Synergy stem has demonstrated excellent clinical and radiological result at midterm and long-term results, but long-term results for dysplastic hips is lacking. The purpose of this study is to evaluate a minimum ten year clinical and radiographic follow-up after THA using single design tapered stems with a one-third proximal porous coating in dysplasia patients.

Patients and methods

We retrospectively evaluated the records of 135 consecutive dysplasia patients (150 hips) who underwent a primary THA using a Synergy cementless femoral stem (Smith & Nephew) at a single institution between December 1999 and October 2009 with the senior surgeon (*I.R.T.*). During this time, 545 primary THAs were performed using only the Synergy stem in 495 patients by the same senior surgeon. During the study, Dorr type A or B proximal femoral morphology was the main indication to use a cementless stem, not patient age [17]. Patients with primary osteoarthritis, femoral head osteonecrosis, rheumatoid arthritis, sequelae of Legg-Calve-Perthes, a previous femoral osteotomy (translation, varus, or valgus), and four patients with Crowe III or IV dysplasia who needed femoral shortening osteotomies were excluded to assess Synergy stem outcomes only in dysplasia patients. There were 112 women (83%) and 23 men (17%) included, with a mean age of 45 years (23 to 72) at the time of surgery. The flow of patients through the study is shown in Fig. 1. The degree of dysplasia was determined using Crowe's classification system [11] which identified 79 hips with grade 2 and 71 hips with grade 3 DDH. Patient demographics are shown in Table 1. All surgeries were performed using a direct lateral Hardinge approach, with an anterior capsulotomy and repair of the anterior third of the fibres of the gluteus medius using intraosseous non-absorbable sutures. All hips were reconstructed with a cementless acetabular component (Reflection Interfit, Smith & Nephew, Memphis, Tennessee). A 28-mm diameter modular femoral head was used in 123 hips; 22-mm diameter in 20 hips, 32-mm diameter in six hips; and 36-mm diameter in one hip. Ceramic on ceramic bearing surfaces were used (Bilox®[®], BioloX forte®[®] CeramTec, Plochingen, Germany) in 110 hips, cobalt-chrome on ultra-high molecular weight polyethylene (UHMWPE) in 21 hips, and zirconia

ceramic on UHMWPE in 19 hips. The synergy stem was used in all hips, and stem size ranged from 8 to 16, with a median size of 12 (Fig. 2). High offset stems were used in 40 hips, with standard offset stems used in all others.

Radiographic evaluation was performed pre-operatively at three months, six months, one year, three years, five years, seven years, ten years, and every three years post-operatively. The Harris Hip Score (HHS) [18] and the Merle D' Aubigne pain and functional score [19] were recorded pre-operatively and at last follow-up visit. In addition, thigh pain was evaluated with the visual analogue scale (VAS) [20] at every clinical visit. All patients were examined within one year of data collection for this study.

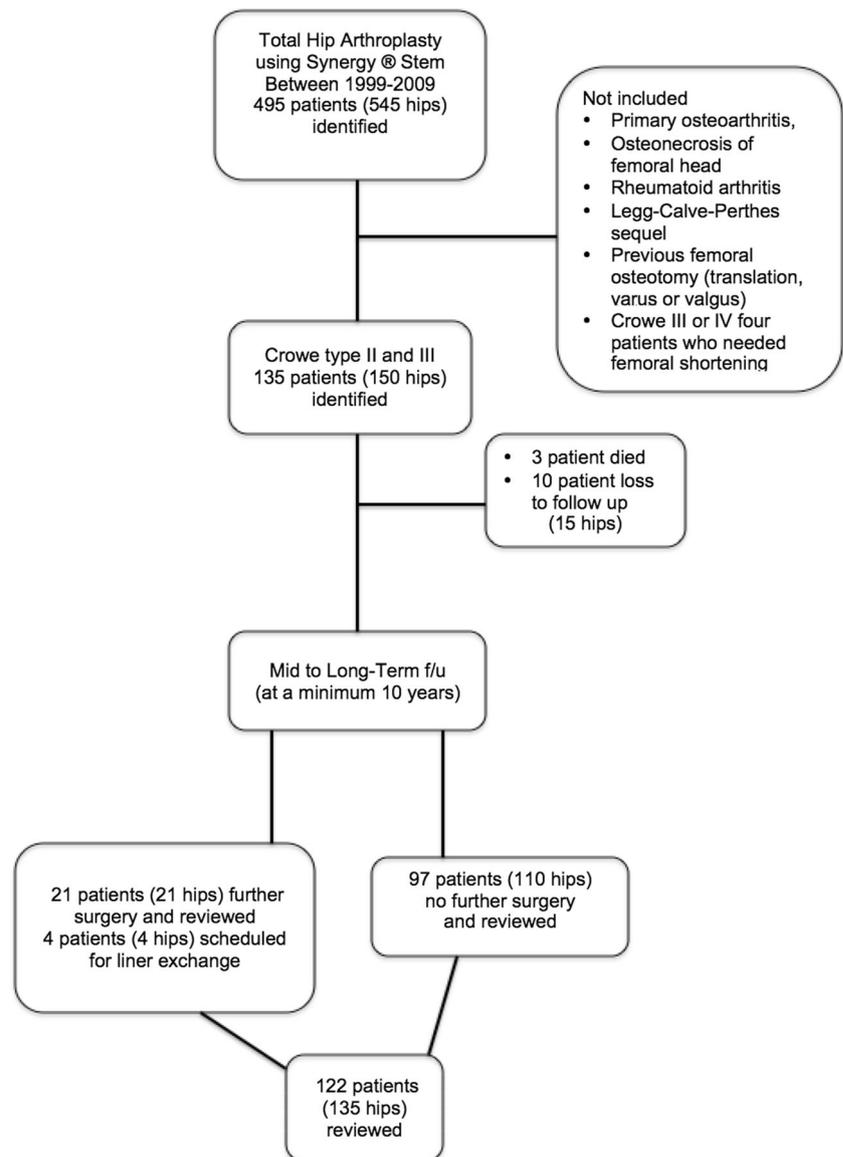
Supine anteroposterior (AP) and lateral radiographs were obtained for all patients before surgery, with serial post-operative follow-ups. The immediate post-operative radiograph was selected as the baseline for the radiographic assessment of the stem. Subsidence, bone ingrowth, radiolucency, osteolysis, loosening, the presence of distal hypertrophy, femoral stress shielding, pedestal formation at the tip of the stem, and heterotopic ossification were recorded.

Loosening was assessed according to radiographic criteria described by Gruen [21]. Stem osseointegration was graded as stable with bony ingrowth, stable fibrous or loose according to Engh et al. [22]. Stems were also assessed for subsidence of more than 2 mm and for changes in alignment (valgus or varus) of more than 2° as described by Martell et al. [23]. We also compared immediate post-operative radiographs with final AP radiographs and recorded adaptive bone changes as either present or absent, which included fusiform enlargement of the cortical bone and distal cortical hypertrophy. [22] Stress shielding was evaluated according to the Engh Classification. Zero- to second-degree stress shielding on final follow-up radiographs was defined as mild, while third- and fourth-degree stress shielding was defined as severe. [24] The Brooker classification was used to assess heterotrophic ossification. [25]

Statistics

Statistical Analysis was performed using MedCalc statistical software version 17.9 (MedCalc Software bvba, Ostend, Belgium; <https://www.medcalc.org>; 2017). Kaplan-Meier survival analysis was used to calculate survivorship curves with 95% confidence intervals (CIs), with end points consisting of stem revision for any reason including aseptic loosening, or revision of any other component (acetabular component, liner, or head). A worst-case scenario was based on the assumption that all patients with insufficient or no follow-up and death underwent a revision between the date of the last clinical visit and the earliest date that the patient could not be located. Harris Hip Scores and Merle D' Aubigne pain and functional

Fig. 1 The flowchart of the patients during study



scores were compared with the Wilcoxon single-rank test. Possible determinants of stress shielding were evaluated with multiple regression analysis: patient demographics (age at the time of surgery, body mass index (BMI)), radiographic factors (Dorr type) and surgical/implant factors (stem size).

Result

A total of three patients died before the minimum 10-year follow-up from causes unrelated to the primary THA. Ten patients were lost to follow-up between six and ten years after surgery. The prostheses of these 13 patients (15 hips) were functional at the time of the last clinical follow-up. A total of 122 patients (135 hips) were therefore available for clinical and radiographic examination (89.9%). The mean follow-up

was 14.7 years (10 to 16.8). Leg length was increased by 15.6 mm (range, 0.5–39 mm) after index arthroplasty.

Clinical outcome Harris Hip Scores significantly improved from 39 (pre-operative) to 92 (most recent visit). Significant improvements were also observed in Merle D' Aubigne pain (2.2 to 5) and functional scores (2.4 to 6). Moderate (five to ten on the VAS scale) thigh pain was reported by six patients (4.9%). One of these six patients had constant, not episodic thigh pain, requiring intramedullary decompression below the tip of the stem. There was no statistically significant difference in the incidence of thigh pain between patients with and without moderate stress shielding.

Radiological outcome No femoral component subsided. One-hundred twenty-six (93%) were in neutral alignment, 7 (5.1%)

Table 1 Patient demographics

Parameters	Value
Patients/hips	122/135
Gender (female/male) patients	102/20
Age of patients at the time of surgery (year)*	45 (23–72)
Body mass index (kg/m ²)*	27.2 (18.8–37.6)
Duration of follow-up (year)*	14.7 (10–16.8)
Bone quality according to Dorr index	
A	70
B	65
Diagnosis	
Developmental Dysplasia of the hip (DDH)	
Crowe type II	74
Crowe type III	61

*Mean value of variables about patients

were in varus (mean 1.8°), and 2 (1.4%) were in valgus after surgery. There was no change in alignment compared with immediate post-operative radiographs of the hips with varus or valgus alignment. According to the Engh criteria for osteointegration, all stems had stable bony ingrowth. Radiolucent lines were present in 1 or 2 zones in 42 hips (31%). All radiolucent lines seen in zones 1 and 7 were less



Fig. 2 The Synergy stem is a titanium alloy straight-tapered stem made of a titanium alloy with a proximal 1/3 circumferential porous coating and distal 2/3 grit blasted with a polished bullet shaped tip. The neck-shaft angle of 131° is maintained in the standard and high offset stem

than 1 mm width and were not progressive. Gruen zone 1, proximal to the porous ingrowth surface, was the most common region in which osteolysis was detected. Osteolysis occurred in Gruen zone 1 in 25 hips (18.5%) and both zone 7 and zone 1 in 11 hips (8.1%). Distal cortical hypertrophy occurred in 21 hips (15.5%): zone 2 in four hips, zone 3 in five hips, and zone 5 in 12 hips. Spot-weld formation was seen in a total of 102 hips (75.4%) in either zones 3 or 5. We did not observe any complete pedestal formation. According to Brooker's classification, three hips had grade-I and four hips had grade-II heterotopic ossification. No grades III or IV heterotopic ossification was observed. At the most recent follow-up after surgery, first-degree stress shielding was recorded in 52 hips, second-degree in 59 hips, third-degree in 19 hips, and fourth-degree in five hips. Multiple regression analysis showed that the degree of stress shielding was not correlated with patient demographics, radiographic characteristics, or implant factors. (Table 2).

Revisions One patient underwent a two-stage revision because of a deep infection that occurred 13.5 years post-operatively. There were no femoral stem revisions due to loosening, wear, periprosthetic fractures, or instability. Two patients had a periprosthetic fracture (Vancouver type B1 and AL) due to a fall and were treated with cable fixation without a femoral stem revision. Five patients had an intra-operative Mallory [26] type I calcar fracture and were treated with single cable fixation. We did not observe any subsidence in these patients. One patient had an osteolytic pathologic fracture of the greater trochanter 12.3 years after the primary THA, which required internal fixation with a grip plate, bone grafting, and revision of the acetabular component only. One patient had a trochanteric avulsion fracture two weeks after the index THA and was treated with a cable-grip plate.

We had four dislocations (2.9%): two acetabular components were revised for recurrent dislocations, while the other two were treated with a closed reduction. Eight hips (5.9%) underwent an isolated liner and head exchange due to wear or osteolysis without an acetabular shell revision (6 were zirconia ceramic on UHMWPE, 2 were cobalt-chrome on UHMWPE). (Fig. 3) The acetabular component in one hip (0.7%) required a revision for loosening secondary to wear. Isolated liner exchanges were recommended in four patients (4 hips), but all declined. These patients were included in the worst-case scenario. We had one acute infection 1 month postoperatively, handled with irrigation and debridement with head and liner exchange (Table 3).

Survival The cumulative survival rate of the Synergy femoral stem was 98% (95% confidence interval [1], 92.5–99.8%) 14 years after THA. (Fig. 4) Using revision for any reason as an end point, the cumulative survival rate of any component was 84% (95% CI, 78.6–89.4%) 14 years after surgery, with a worst-case scenario of 76.3% (95% CI, 65.5–81.5%) (Fig. 5).

Table 2 Multiple regression analysis showed that independent factors had no significantly severe stress shielding effect

Factors	Coefficient	Standard error	95%CI	t-value	p value
Intercept	0.2560	1.1311	−0.78 to 0.59	1.9526	0.073
BMI	−0.01251	0.01139	−0.03 to 0.01	−1.0982	0.27
Dorr type (A. B.)	−0.1845	0.1584	−0.65 to 0.22	−1164	0.24
Age	0.01128	0.00708	−0.07 to 0.003	1593	0.56
Height	−0.2115	0.01678	−0.20 to 0.61	−1059	0.39
Stem size	0.1296	0.1723	−0.04 to 0.01	−1059	0.29
Distal hypertrophy	0.02667	0.0687	−0.10 to 0.16	1387	0.69

Discussion

This is the largest study to our knowledge that reviews primary total hip arthroplasty using dual offset one-third proximally porous coated tapered stems in dysplastic hips. This study demonstrates excellent survivorship and clinical outcomes with the HHS, Merle D' Aubigne pain and functional score, as well as the VAS score for thigh pain. There was also a low ratio of stress shielding after a minimum ten year follow-up.

There is no accurate consensus regarding the direct use of modular or non-modular cementless stems for dysplasia patients who have undergone a primary THA with or without femoral shortening osteotomy [27–30]. Wagner cone-type non-modular tapered stems demonstrated excellent stability, osteointegration, and orientation capacity in dysplastic hips at mid- to long-term follow-up [29, 30]. The main advantage of cone type-tapered stems is the placement in any anteversion orientation by the surgeon. Only one paper focused on the selection of modular vs. non-modular tapered stems based on preoperative neck-shaft angle to decrease dislocation rate in dysplasia patients. However, this study had a limited

number of patients that prevented accurate cut-off values [31]. Also, metaphyseal-filling tapered stems also had excellent stability and survivorship in dysplasia patients [5]. In addition, our study demonstrated acceptable complication rate at early postoperative period (dislocation 2.9%, intraoperative calcar fracture 3.7%) and long-term follow up (survival 98% for 14 years) for Synergy stem.

Excessive valgus angulation of the femoral neck, small-sized femoral neck or canal, and abnormal anteversion can predispose to malalignment of the stem and peri-operative calcar fracture in dysplastic hips [12, 14–16, 32]. Also, fixed neck-shaft angle of the tapered stems shows some differences according to the manufacturer; dual offset stem (131°) have lower neck-shaft angle than Wagner cone type femoral stem (135°). Stems, which have higher neck-shaft angle, may be more suitable to prevent peri-operative calcar fractures for dysplastic hips. Also Synergy stem, which has a higher medio-lateral width than anterior-posterior width at the level of calcar, may not be appropriate for excessive valgus angulated and under-sized femoral neck. The incidence of peri-operative calcar fracture was higher with Synergy stem

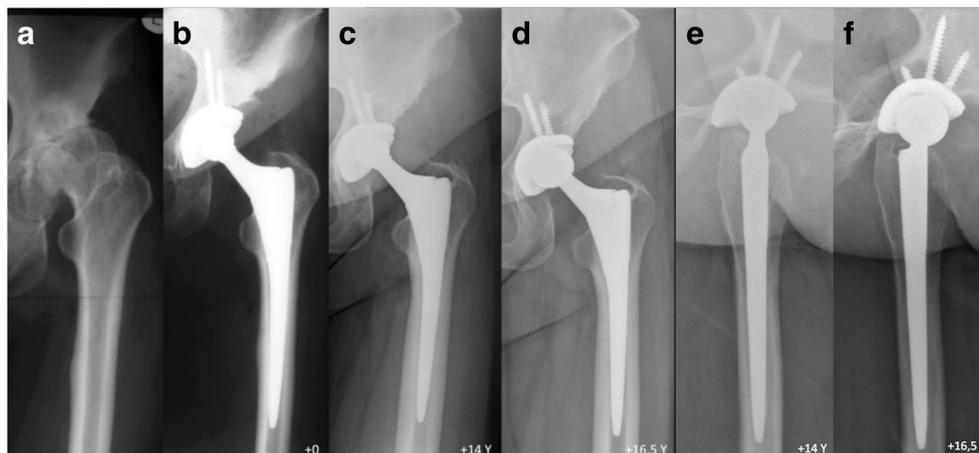


Fig. 3 Anterior-posterior radiographs of a 39-year-old woman with left hip arthritis secondary to Crowe type II dysplasia (a), immediate position of THA with 22 mm zirconia ceramic femoral head (b) polyethylene liner wear and osteolysis after 14 years (c), and last follow-up image after

femoral head and liner exchange (d). The image show the positioning of the stem in lateral view before (e) and after revision surgery and first-degree stress shielding around the stem, although osteolysis is observed only in zone 1 after 16.5 years (f)

Table 3 Complications and revised components during study

Variable	Values
Femoral component revision	1/135 (0.7)
Deep PI	1
Acetabular component revision	4/135 (2.9)
Dislocation	2
Loosening	1
Deep PI	1
Head and liner exchange	9/135 (6.6)
Wear and osteolysis	8
Acute PI	1
Perioperative calcar fracture	5/135 (3.7)
Periprosthetic fracture	4/135 (2.9)
Osteolysis	2
Traumatic	2
Type of bearing surface	
Ceramic-ceramic	1/95 (1.05)
Cobalt-chrome on polyethylene	3/21 (14.2)
Zirconia ceramic on polyethylene	9/19 (47.3)

PPI periprosthetic infection

(0.89 to 3.3%) than cone-type stem (0–2.8%) [4, 10, 30]. However, Synergy stem showed nearly similar rate (3.7%) of peri-operative calcar fracture in dysplastic femurs in the current study like previous reported data for primary osteoarthritis (3.3%) series [4].

Nishino et al. found that no Synergy stem required an aseptic revision in their minimum ten year follow-up study on 50 hips (44 hips had dysplasia) [5]. The largest retrospective study that compared the ten year clinical and radiographic

results of cylindrical (185 Prodigy) and tapered stems (327 Synergy stem) showed a 97.5% survivorship, with aseptic revision as the end point [6]. Martino et al. had the longest follow-up period in their retrospective study that included 94 hips in 85 patients. The cumulative survivorship of the Synergy stem was 98.9%, with stem revision for aseptic loosening as the endpoint, and 95.7% with stem revision for any reason as the endpoint [10]. The long-term results of our cohort are nearly same as previously published with the same tapered designs, with excellent survivorship at 98% after a mean follow-up of 14.7 years in dysplasia patients.

Many factors are known to contribute to increased stress shielding, which include both implant (stem diameter, rigidity, elasticity) and patient factors (bone mineral density, age, sex, time since the index surgery, patient height and/or weight) [33–39]. As expected with metaphyseal fixation, we found no severe change in stress shielding, with findings nearly identical to previously published papers on the same stem [6, 10]. We observed stress shielding around all stems, but severe stress shielding was present only in 5 (3.7%) hips (fourth degree), with moderate involvement in 19 (14%) hips (third degree). However, a higher rate of severe stress shielding was reported in 23 hips (46%, 23 of 53 hips) with the same stem at ten year follow-up by Nishino et al [5]. Their multiple regression analysis also showed a positive correlation between stress shielding and stem size (13 or larger in short stature patients), as well as a negative correlation with patient height. In our study, multiple regression analysis showed that the degree of stress shielding was not correlated with patient demographic, radiographic, or implant factors in dysplastic hips. With respect to radiographic bone changes around the stem, spot-weld formation (75.4%) commonly noted at the

Fig. 4 The graph shows the cumulative survival rate of femoral stem was 98% at 14.7 years, taking revision for any reason as an end point

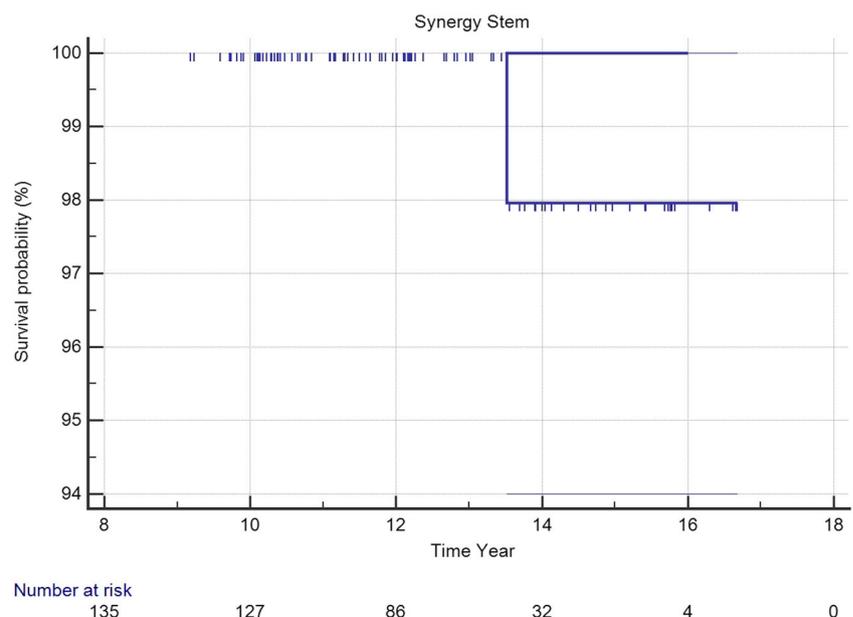
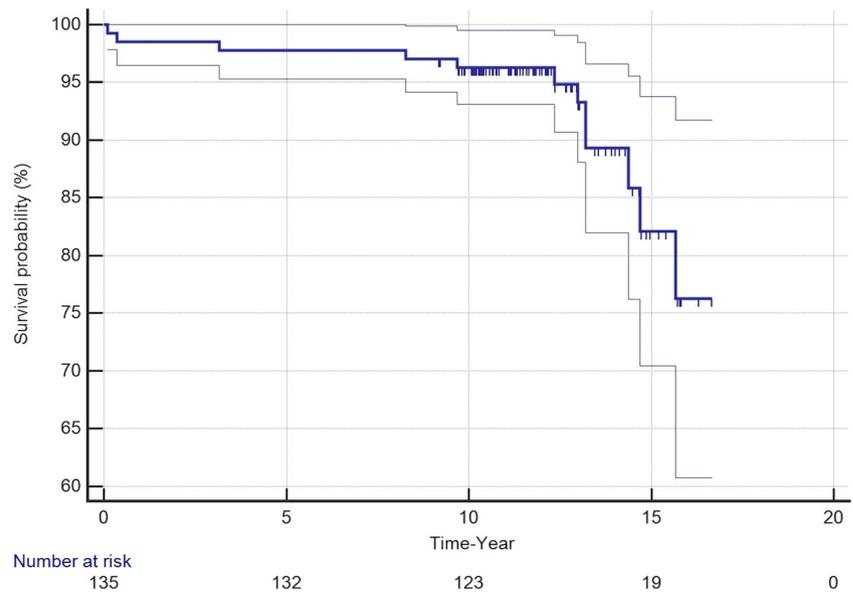


Fig. 5 The graph shows the cumulative survival rate of total hip system



border of the distal polished end (zones 3 and zone 5) in our study. This result was nearly the same as previously published work that also showed that bone remodeling occurred beyond the proximal metaphyseal area [5].

There are several limitations in this study. The first is that this study had no control group and was not randomized, a fact that could bias the results. Moreover, a considerable number of patients (135 hips, 89.9%) had complete radiographic and clinical findings that permitted the evaluation of long-term stem performance. Second, loosening, osteolysis, radiolucent lines, and stress shielding were evaluated only on AP and lateral radiographs. Other examination methods should be used to evaluate bone density and stress shielding more accurately, such as dual-energy X-ray absorptiometry. One of the selection criteria for cementless THA: Dorr index (Dorr A and B femurs) could bias the results, as recent reports showed excellent results using cementless tapered stems in Dorr C femurs [40]. We had same design acetabular cups with different bearing surfaces, and bearings have no effect on stem survival after a mean 14.7-year follow-up. However, bearings may influence the survivorship of the stem in further follow-ups at second decade.

This study demonstrates that dual offset tapered stems had excellent survivorship and stability, good clinical outcome scores with low thigh pain and stress shielding, and may be a suitable option for a primary total hip arthroplasty for arthritis secondary to developmental dysplasia of the hip.

Acknowledgements IRB of Acibadem University, Acibadem School of Medicine approved this clinical study. Date: 12 May 2016 Number: ATADEK 2016-8/17.

Authors' contribution All the authors designed the study, revised the manuscript, and approved the final draft.

Compliance with ethical standards

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

References

1. Khanuja HS, Vakil JJ, Goddard MS, Mont MA (2011) Cementless femoral fixation in total hip arthroplasty. *J Bone Joint Surg Am* 93(5):500–509. <https://doi.org/10.2106/JBJS.J.00774>
2. Dorr LD, Lewonowski K, Lucero M, Harris M, Wan Z (1997) Failure mechanisms of anatomic porous replacement I cementless total hip replacement. *Clin Orthop Relat Res* (334):157–67
3. Engh CA, Powers CC, Ho H, Beykirch-Padgett SE, Hopper RH Jr, Engh CA Jr (2012) The effect of poly sterilization on wear, osteolysis and survivorship of a press-fit cup at 10-year follow-up. *Clin Orthop Relat Res* 470(2):462–470. <https://doi.org/10.1007/s11999-011-2052-2>
4. Danesh-Clough T, Bourne RB, Rorabeck CH, McCalden R (2007) The mid-term results of a dual offset uncemented stem for total hip arthroplasty. *J Arthroplast* 22(2):195–203. <https://doi.org/10.1016/j.arth.2006.04.006>
5. Nishino T, Mishima H, Kawamura H, Shimizu Y, Miyakawa S, Ochiai N (2013) Follow-up results of 10-12 years after total hip arthroplasty using cementless tapered stem – frequency of severe stress shielding with synergy stem in Japanese patients. *J Arthroplast* 28(10):1736–1740. <https://doi.org/10.1016/j.arth.2013.02.027>
6. Petis SM, Howard JL, McAuley JP, Somerville L, McCalden RW, MacDonald SJ (2015) Comparing the long-term results of two uncemented femoral stems for total hip arthroplasty. *J Arthroplast* 30(5):781–785. <https://doi.org/10.1016/j.arth.2014.07.024>
7. Bugbee WD, Culpepper WJ 2nd, Engh CA Jr, Engh CA Sr (1997) Long-term clinical consequences of stress-shielding after total hip arthroplasty without cement. *J Bone Joint Surg Am* 79(7):1007–1012
8. Kim YH (2005) Long-term results of the cementless porous-coated anatomic total hip prosthesis. *J Bone Joint Surg (Br)* 87(5):623–627. <https://doi.org/10.1302/0301-620X.87B5.15554>

9. Nourbash PS, Paprosky WG (1998) Cementless femoral design concerns. Rationale for extensive porous coating. *Clin Orthop Relat Res* (355):189–199
10. De Martino I, De Santis V, D'Apolito R, Sculco PK, Cross MB, Gasparini G (2017) The synergy cementless femoral stem in primary total hip arthroplasty at a minimum follow-up of 15 years. *Bone Joint J* 99-B(1):29–36. <https://doi.org/10.1302/0301-620X.99B1.BJJ-2016-0231.R1>
11. Crowe JF, Mani VJ, Ranawat CS (1979) Total hip replacement in congenital dislocation and dysplasia of the hip. *J Bone Joint Surg Am* 61(1):15–23
12. Noble PC, Kamaric E, Sugano N, Matsubara M, Harada Y, Ohzono K, Paravic V (2003) Three-dimensional shape of the dysplastic femur: implications for THR. *Clin Orthop Relat Res* 417:27–40
13. Sugano N, Noble PC, Kamaric E, Salama JK, Ochi T, Tullos HS (1998) The morphology of the femur in developmental dysplasia of the hip. *J Bone Joint Surg (Br)* 80(4):711–719
14. Fitzgerald RH, Jr, Brindley GW, Kavanagh BF (1988) The uncemented total hip arthroplasty. Intraoperative femoral fractures. *Clin Orthop Relat Res* (235):61–66
15. Perka C, Fischer U, Taylor WR, Matziolis G (2004) Developmental hip dysplasia treated with total hip arthroplasty with a straight stem and a threaded cup. *J Bone Joint Surg Am* 86-A(2):312–319
16. Moroni A, Faldini C, Piras F, Giannini S (2000) Risk factors for intraoperative femoral fractures during total hip replacement. *Ann Chir Gynaecol* 89(2):113–118
17. Dorr LD, Faugere MC, Mackel AM, Gruen TA, Bogner B, Malluche HH (1993) Structural and cellular assessment of bone quality of proximal femur. *Bone* 14(3):231–242
18. Harris WH (1969) Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 51(4):737–755
19. D'Aubigne MM (1954) Bilateral congenital hip dislocation aggravated by osteotomies. *Rev Chir Orthop Reparatrice Appar Mot* 40(3–4):447–448
20. Laupacis A, Bourne R, Rorabeck C, Feeny D, Wong C, Tugwell P, Leslie K, Bullas R (1993) The effect of elective total hip replacement on health-related quality of life. *J Bone Joint Surg Am* 75(11):1619–1626
21. Gruen TA, McNeice GM, Amstutz HC (1979) “Modes of failure” of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* (141):17–27
22. Engh CA, Bobyn JD, Glassman AH (1987) Porous-coated hip replacement. The factors governing bone ingrowth, stress shielding, and clinical results. *J Bone Joint Surg (Br)* 69(1):45–55
23. Martell JM, Pierson RH 3rd, Jacobs JJ, Rosenberg AG, Maley M, Galante JO (1993) Primary total hip reconstruction with a titanium fiber-coated prosthesis inserted without cement. *J Bone Joint Surg Am* 75(4):554–571
24. Engh CA, Massin P, Suthers KE (1990) Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. *Clin Orthop Relat Res* (257):107–128
25. Brooker AF, Bowerman JW, Robinson RA, Riley LH Jr (1973) Ectopic ossification following total hip replacement. Incidence and a method of classification. *J Bone Joint Surg Am* 55(8):1629–1632
26. Mallory TH, Kraus TJ, Vaughn BK (1989) Intraoperative femoral fractures associated with cementless total hip arthroplasty. *Orthopedics* 12(2):231–239
27. Grappiolo G, La Camera F, Della Rocca A, Mazziotta G, Santoro G, Loppini M (2018) Total hip arthroplasty with a monoblock conical stem and subtrochanteric transverse shortening osteotomy in Crowe type IV dysplastic hips. *Int Orthop*. <https://doi.org/10.1007/s00264-018-4122-5>
28. Zagra L, Bianchi L, Mondini A, Ceroni RG (2015) Oblique femoral shortening osteotomy in total hip arthroplasty for high dislocation in patients with hip dysplasia. *Int Orthop* 39(9):1797–1802. <https://doi.org/10.1007/s00264-015-2865-9>
29. Faldini C, Miscione MT, Chehrassan M, Acri F, Pungetti C, d'Amato M, Luciani D, Giannini S (2011) Congenital hip dysplasia treated by total hip arthroplasty using cementless tapered stem in patients younger than 50 years old: results after 12-years follow-up. *J Orthop Traumatol* 12(4):213–218. <https://doi.org/10.1007/s10195-011-0170-y>
30. Faldini C, Nanni M, Leonetti D, Miscione MT, Acri F, Giannini S (2011) Total hip arthroplasty in developmental hip dysplasia using cementless tapered stem. Results after a minimum 10-year follow-up. *Hip Int* 21(4):415–420. <https://doi.org/10.5301/HIP.2011.8588>
31. Peters CL, Chrastil J, Stoddard GJ, Erickson JA, Anderson MB, Pelt CE (2016) Can radiographs predict the use of modular stems in developmental dysplasia of the hip? *Clin Orthop Relat Res* 474(2):423–429. <https://doi.org/10.1007/s11999-015-4458-8>
32. Ohishi M, Nakashima Y, Yamamoto T, Motomura G, Fukushi JI, Hamai S, Kohno Y, Iwamoto Y (2016) Cementless total hip arthroplasty for patients previously treated with femoral osteotomy for hip dysplasia: the incidence of periprosthetic fracture. *Int Orthop* 40(8):1601–1606. <https://doi.org/10.1007/s00264-015-2992-3>
33. Bobyn JD, Glassman AH, Goto H, Krygier JJ, Miller JE, Brooks CE (1990) The effect of stem stiffness on femoral bone resorption after canine porous-coated total hip arthroplasty. *Clin Orthop Relat Res* (261):196–213
34. Sumner DR, Galante JO (1992) Determinants of stress shielding: design versus materials versus interface. *Clin Orthop Relat Res* (274):202–212
35. Weinans H, Huiskes R, Grootenboer HJ (1992) Effects of material properties of femoral hip components on bone remodeling. *J Orthop Res* 10(6):845–853. <https://doi.org/10.1002/jor.1100100614>
36. Huiskes R, Weinans H, van Rietbergen B (1992) The relationship between stress shielding and bone resorption around total hip stems and the effects of flexible materials. *Clin Orthop Relat Res* 274:124–134
37. D'Antonio JA, Capello WN, Manley MT (1996) Remodeling of bone around hydroxyapatite-coated femoral stems. *J Bone Joint Surg Am* 78(8):1226–1234
38. Wixson RL, Stulberg SD, Van Flandern GJ, Puri L (1997) Maintenance of proximal bone mass with an uncemented femoral stem analysis with dual-energy x-ray absorptiometry. *J Arthroplast* 12(4):365–372
39. MacDonald SJ, Rosenzweig S, Guerin JS, McCalden RW, Bohm ER, Bourne RB, Rorabeck CH, Barrack RL (2010) Proximally versus fully porous-coated femoral stems: a multicenter randomized trial. *Clin Orthop Relat Res* 468(2):424–432. <https://doi.org/10.1007/s11999-009-1092-3>
40. Dalury DF, Kelley TC, Adams MJ (2012) Modern proximally tapered uncemented stems can be safely used in Dorr type C femoral bone. *J Arthroplast* 27(6):1014–1018. <https://doi.org/10.1016/j.arth.2011.12.019>