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ORIGINAL ARTICLE

Highly Cross-Linked Polyethylene in Cementless Total Hip Arthroplasty in Patients with Previous Acetabular Fractures: A Minimum 5-Year Follow-Up Study

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Abstract

Background Outcomes of THA after acetabular fracture are generally less favorable than those of the nontraumatic arthritis due to a higher rate of cup loosening and osteolysis. We, therefore, investigated whether highly cross-linked polyethylene liners positively impact outcomes of THA in patients with posttraumatic osteoarthritis after acetabular fracture.

Methods We retrospectively evaluated 39 patients with previous acetabular fracture who underwent THA using highly cross-linked polyethylene liner after a mean 8.5 year follow-up. All procedures were performed at a single institution by a single surgeon using the same type of THA implants. Wear measurements were performed using a computer-assisted PolyWare software. Osteolysis was evaluated with use of radiography and computed tomography.

Results The mean preoperative Harris hip score was 44.4 points, which improved to 93.1 points at final follow-up. Neither femoral nor acetabular components displayed mechanical loosening and no components had been revised. Radiographs and CT scans did not demonstrate osteolysis. The mean linear wear was 0.043 mm/y (range 0–0.098 mm/y). With the data available, univariate regression analysis suggests that age, gender, weight, initial fracture type, the duration of follow-up, activity level, liner thickness, acetabular cup inclination, and the necessity of bone graft had no influence on liner penetration.

Conclusion While the long-term effects of the polyethylene particles from highly cross-linked polyethylene remain unknown, implant survivorship and wear data in this study are promising for this high-risk population. Our encouraging results support the continued use of this type of polyethylene in patients after acetabular fractures.

Level of Evidence Level IV Therapeutic study.

Keywords Acetabular fracture · Posttraumatic osteoarthritis · Total hip arthroplasty · Highly cross-linked polyethylene

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Abbreviations

THA	Total hip arthroplasty
HXLPE	Highly cross-linked polyethylene
ORIF	Open reduction and internal fixation
UHMWPE	Ultra-high-molecular-weight polyethylene
MRSA	Methicillin-resistant *Staphylococcus aureus*
CT	Computed tomography
TIFF	Tagged image file format

Introduction

Total hip arthroplasty (THA) is frequently performed as a salvage procedure for acetabular fractures. However, outcomes of THA following acetabular fractures are generally less favorable than those of the nontraumatic arthritis due to high rate of cup loosening and osteolysis [1]. The higher activity level of younger patients has been proposed as a factor contributing to these high failure rate [2]. Other important reasons include acetabular bone deficiency and compromised bone quality. Special considerations for this situation should be taken for previous surgical exposure with dense scar tissue, the type and location of implants, the location and amount of heterotopic ossification, indolent infection, previous sciatic nerve palsy, and the pathoanatomy. These factors can influence the choice of surgical exposure and the reconstructive method. Recently, high rates of polyethylene (PE) wear and secondary osteolysis remain challenging problem in young, active patients undergoing THA because of long lifespans [3]. Although alternative bearing surfaces have shown to markedly reduced osteolysis in young patients [4–7], the outcomes of THA with highly cross-linked PE (HXLPE) in patients with previous acetabular fractures have not been reported. We, therefore, investigated whether HXLPE liners would lead to favorable outcomes for patients with previous acetabular fractures. In addition, we also determined the rate of PE wear and the prevalence of periprosthetic osteolysis.

Materials and Methods

The Study Group

We performed 43 consecutive cementless THA with previous acetabular fractures using the HXLPE between 2001 and 2012. We followed these patients at the time of scheduled patient visits to evaluate the clinical and radiographic outcomes. In total, four hips were lost to follow-up before the end of the minimum 5 years; none of the four patients required implant revision at the time of their last evaluation.

The 39 remaining patients were included in this retrospective study (Table 1). The mean age of the patients at the time of the accident was 50.5 years (range 22–80 years) and 54.4 years (range 29–81 years) at the time of THA. All patients provided written informed consent, and our Institutional Review Board approved the protocol. The mean follow-up period was 8.5 years (range 5.0–15.7 years). The initial fracture pattern was classified by the method of Judet et al. [8], 31 cases of simple fracture and eight cases of associated fracture (Table 2). The acetabular fracture was treated

Table 2 Acetabular fracture pattern (Leutonel and Judet)

Fracture pattern	ORIF	Non-ORIF	Total (%)
Elementary			31 (79.5%)
Anterior column		1	
Posterior column	20	9	
Posterior wall[a]			
Transverse			
Associated			8 (20.5%)
Anterior + posterior hemitransverse	2		
Both column	2	1	
Posterior column + posterior wall	1		
Transverse + posterior wall	2		
Total (%)	27 (70%)	12 (30%)	

ORIF open reduction and internal fixation

Table 1 Patient demographics

Patient characteristics	ORIF	Non-ORIF	Total (%)	*p* value
Age at fracture (years)	48.56 ± 14.38	56.42 ± 11.35	50.97 ± 10.57	0.103
Gender (male, female)	(27:0)	(10:2)	(37:2)	0.089
Body mass index (kg/m^2)	23.66 ± 3.11	22.73 ± 2.92	23.37 ± 3.05	0.323
Age at THA (years)	51.56 ± 12.56	61.58 ± 8.73	54.64 ± 12.33	0.006
Side (right, left)	(14:13)	(5:7)	(19:20)	0.557
Activity level (hips) (%)				
Heavy labor	3 (11.1)	3 (25.0)	6 (15.4)	–
Moderate labor	16 (59.3)	5 (41.7)	21 (53.8)	
Light labor	8 (29.6)	4 (33.3)	12 (30.8)	
Time elapsed between fracture and THA	26.85 ± 44.76	92.50 ± 137.15	47.05 ± 88.08	0.266
Operation time for THA (min)	208.15 ± 71.95	165.42 ± 56.06	195.00 ± 69.65	0.077
Length of follow-up (years)	8.08 ± 2.90	9.56 ± 3.03	8.53 ± 2.98	0.144
Cup size (mm)	62.41 ± 4.13	60.33 ± 4.05	61.77 ± 4.16	0.154
Stem size (mm)	10.52 ± 2.40	10.75 ± 2.70	10.59 ± 2.47	0.758
Cup abduction angle (°)	40.96 ± 3.31	42.00 ± 3.30	41.28 ± 3.30	0.372
Necessity of bone graft (yes, no)	(17:10)	(5:7)	(22:17)	0.216
Preoperative Harris hip score	45.52 ± 12.98	39.92 ± 7.81	43.80 ± 11.82	0.175

The values are given the mean and standard deviation nonoperative in 12 (30%) patients and open reduction and internal fixation (ORIF) in 27 (70%). Kocher–Langenbeck approach was used in 22 patients, ilioinguinal approach in 3, and a combined approach in 2. There were 37 men and 2 women with a mean height of 168.9 cm (range 150–184 kg), a weight of 66.9 kg (range 49–89 kg), and a body mass index (BMI) of 23.4 kg/m^2 (range 19–30.8 kg/m^2).

Prosthesis

Cementless THA with HXLPE was performed in all hips. Two different cementless hip systems were used because of the evolving inventory at our hospital. Thirteen patients received an HXLPE (Durasul®, Zimmer, Warsaw, IN), a cementless acetabular cup (Converge®, Zimmer, Warsaw, IN), and a 28-mm cobalt–chromium femoral head between 2001 and 2005. Twenty-six patients received another HXLPE (Longevity®, Zimmer, Warsaw, IN), a cementless acetabular cup (Trilogy®, Zimmer, Warsaw, IN), and either a 28 mm (four patients) or a 36-mm (22 patients) cobalt–chromium femoral head between 2006 and 2012. We implanted 36-mm heads except for in instances when a shell smaller than 58 mm was required. Elevated liners were used to enhance stability in 16 (41%) hips. The CLS stem was utilized in all patients, because the patients were young and active and had sufficiently good bone quality (Dorr type A or B) [9].

Surgical Procedure

Anterolateral approach was used and the procedures were performed by the same surgeon (BWM). Staged debridement with hardware removal before THA was undertaken in three patients due to a concern for deep infection (Table 3). The femoral head resected at the time of debridement followed by insertion of cement spacer, and all patients were treated with intravenous antibiotics. Cultures taken at the time of debridement showed no growth in two patients and methicillin-resistant *Staphylococcus aureus* in one. THA conversion was undertaken when inflammatory markers had returned to normal after an antibiotic holiday of at least 2 weeks. Since all patients suspected of infection showed 0–1 polymorphonuclear leukocyte observed under a microscope at high magnification (×400) in more than ten different parts, THA was conducted [9]. The external diameter of the acetabular component averaged 61.8 mm (range 52–70 mm). The average thickness of the PE at the pole was 12.2 mm (range 6.8–15.7 mm). Acetabular defects were classified according to the Paprosky's classification [10]: 22 without significant defects, nine with type I defects, and nine with type II defects. The acetabular defects occurred in 13 hips (48.1%) in the ORIF group and 4 hips (33.3%) in the non-ORIF group ($p > 0.05$). Morselized cancellous graft was impacted into the acetabulum. No structural grafts were required to provide column support. Two patients had radiographic evidence of heterotopic ossification before THA, but required no excision, because they did not interfere with the approach or fitting of the components. All patients had antibiotic prophylaxis for 24 h and thromboembolic prophylaxis with low-molecular-weight heparin for 30 days. The postoperative rehabilitation protocol was the same for all patients, who were allowed progressive weight bearing as tolerated on the third day after surgery.

Evaluation

The clinical evaluation included a physical examination, and calculation of the preoperative and postoperative Harris hip scores (HHS) [11]. The activity level was categorized into six grades [12], one (heavy manual labor); two (moderate manual labor); three (light labor); four (semisedentary); five (sedentary); and six (bedridden or confined to wheelchair).

The primary radiographic outcomes were revision and incidence of complications. Secondary outcomes were radiographic signs of heterotopic ossification or implant loosening. Radiographs taken 4 weeks after the index operation served as the baseline for all subsequent comparisons. According to Massin et al. [13], the cup position was assessed by the height of the center of the hip and the horizontal distance of the cup. The restoration of the hip center was defined as horizontal or vertical variation less than 10 mm respect to the opposite hip. An acetabular component

Table 3 Patients treated with staged debridement and THA

Patient number	Age (years)	Sex	Medical comorbidities	Reason for staged operation	Time between ORIF and debridement (months)	Culture results	Time from debridement to THA (months)	Recurrent infection
1	54	Male	Tobacco use	Rapid joint destruction	3	No growth	5	No
2	29	Male	Tobacco use	History of infection	1	MRSA	72	No
3	58	Male	DM, HTN	Rapid joint destruction	14	No growth	7	No

DM diabetes mellitus, *HTN* hypertension, *MRSA* methicillin-resistant *staphylococcus aureus* was considered radiographically loose when migration occurred or a circumferential radiolucency of 2 mm was noted. Evidence of cup migration was measured on serial radiographs, and a linear change of greater than 3 mm or a rotational change of 8° or greater was considered migration [12]. Femoral component stability and osseointegration were assessed according to the method of Zicat et al. [14]. We used radiographic evaluations of the socket using DeLee and Charnley zones [15] and those of the femur using the Gruen et al.'s [16] system. PE wear was determined using a computer-assisted method with PolyWare software (Draftware Developers, Vevay, IN, USA) [17]. To reduce the disproportionate effects of embedding and creep, the initial radiograph used was that taken 6 months after surgery [18]. Heterotopic ossification was classified according to the Brooker's classification [19]. The metal artifact minimization CT scans were assessed for the presence of osteolysis using Siemens AG (Munich, Germany) with 1 mm collimation, a pitch of 1.5, and a 14–22 cm field of view. The area within 5 cm from the prosthesis–bone interface in all direction was evaluated. CT images were acquired in 33 hips (84.6%) due to high cost and fear of radiation hazards at an average follow-up time of 7.8 years (range 5–12.4 years).

Statistical Analysis

Statistical analysis was performed with SPSS software (version 12.0; SPSS, Chicago, Illinois). The Student's *t* test and Mann–Whitney test were used to compare outcomes in the non-ORIF and ORIF group and HHS. Univariate regression analysis was used to evaluate the relationship between wear and other variables. The level of significance was $p < 0.05$. We performed Kaplan–Meier survivorship analysis for all hips, with the revision of either component as an endpoint.

Results

Revision and Survivorship

Neither femoral nor acetabular components displayed mechanical loosening or periprosthetic osteolysis, and no components were revised. The survivorship for the endpoint of component revision for any cause was 100% (95% confidence interval [CI], 96–100%) at a mean of 8.5 years after surgery.

Clinical Results

Mean preoperative HHS was 44.4 (range 25–85), which improved to 93.1 (range 78–99) at the final follow-up. There was no significant difference between the ORIF and non-ORIF groups. Two patients (5%) had slight thigh pain that was not associated with loosening which did not limit activity. No patient required any kind of walking support at the time of the last follow-up.

Radiographic Results

Mean cup abduction angle was 41.2° (range 36–49°) and all acetabular and femoral components were fixed by bony ingrowth. One hip (2.6%) had radiolucent lines around zone one and two of the acetabular component without evidence of component loosening. On the femoral side, radiolucent lines were found in two hips (5.1%) in zones one and seven, but they did not progress during the follow-up period. In all patients, the reconstructed hip center was repositioned within 10 mm of vertical and horizontal symmetry to the contralateral hip. First-degree stress shielding was observed in two hips (5.1%). Calcar resorption was the only observed bone loss in the femur. No hips had > 5 mm of subsidence of the femoral stem. Heterotopic ossification had developed in two hips (5.1%). One hip had grade one and another one hip had grade two. The mean rate of PE liner wear was 0.043 mm/y (range 0–0.098 mm/y). At the last follow-up, no hip was an outlier for the osteolysis threshold of 0.10 mm/y [3, 20] (Fig. 1). With the data available, univariate regression analysis demonstrated that age, gender, weight, initial fracture type, type of bone defect, initial treatment method of fracture, the duration of follow-up, activity level, liner thickness, acetabular cup inclination, and the necessity of bone graft had no influence on PE liner penetration. Radiographs and CT scans demonstrated no acetabular or femoral osteolysis at the time of the last follow-up (Fig. 1).

Complications

Intraoperative complication included a calcar fracture in two hips and showed good healing with the use of circumferential wiring. There was no dislocation or any clinical evidence of venous thrombosis. A periprosthetic femoral fracture occurred around a well-fixed stem in one patient at 11 months postoperatively. This fracture healed with ORIF. No patients developed deep or superficial infections and had new or progressive sciatic nerve symptoms.

Discussion

Our study demonstrated that contemporary cementless THA using an HXLPE are associated with excellent clinical and radiographic results at an average follow-up of 8.5 years for high-risk patients with previous acetabular fractures.

The limitations of this study include the retrospective design, the small number of patients (39 hips), and the relatively short-term follow-up period (an average of

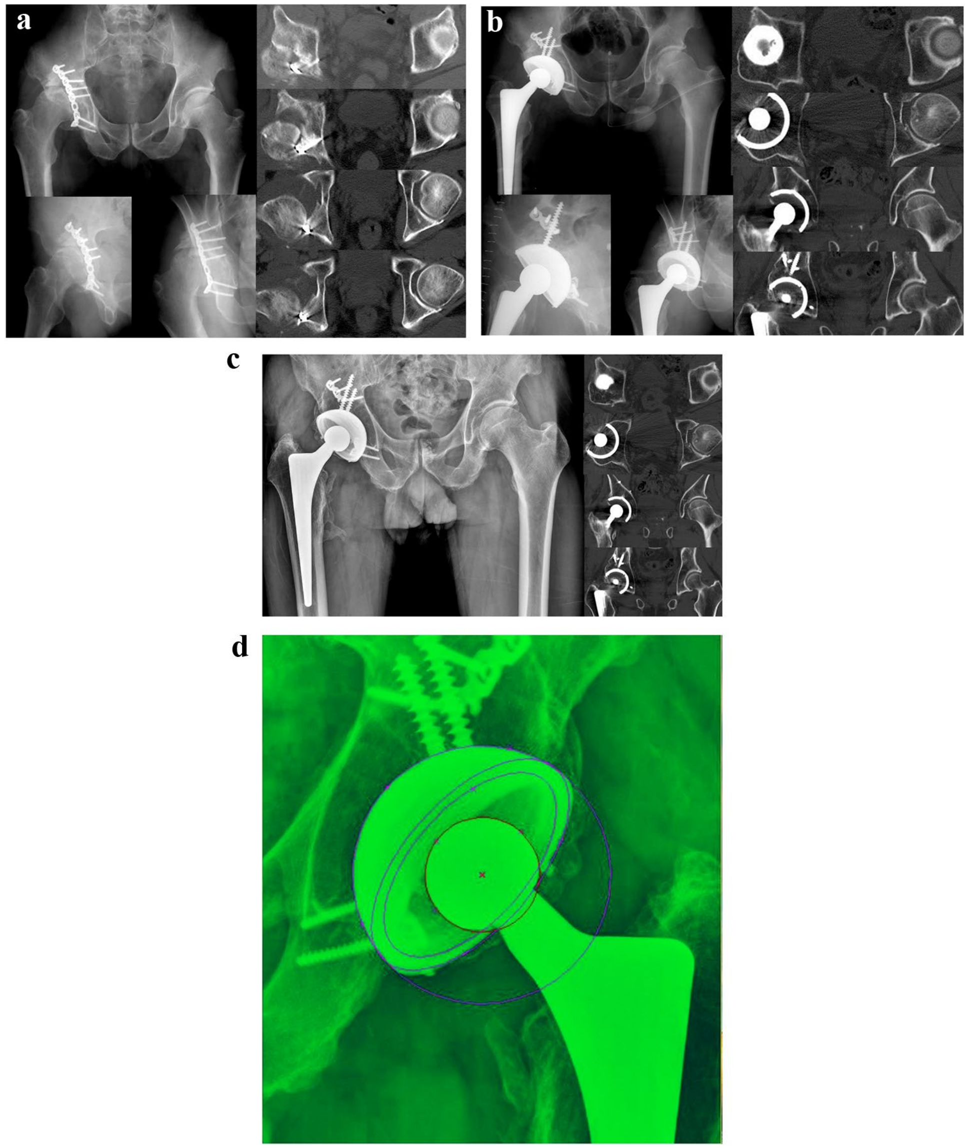

Fig. 1 **a–c** A **55**-year-old man underwent THA with a highly cross-linked polyethylene acetabular liner (Durasul®) to treat traumatic arthritis of the right hip secondary to fracture dislocation hip with posterior wall and transverse acetabulum fracture. (**a**) Radiographs and CT scans obtained 1 week before the primary THA reveals a posterolateral defect with superolateral subluxation of the femoral head. (**b**) Radiographs and CT scans obtained 1 week after THA show a well-fixed cup and stem with restoration of bone defect and hip center. Posterior wall and superior defects are grafted with femoral head autograft. (**c**) Radiograph and CT scans obtained 13 years after THA show no demonstrable radiographic evidence of mechanical loosening or periprosthetic osteolysis of the pelvis or femur. (**d**) Computer-generated analysis at last follow-up. The total penetration was 0.411 mm at 13 years

8.5 years). We also did not use a control group (conventional PE) or all the possible variables to compare outcomes with HXLPE liner, which could not draw exact effect of HXLPE in patients with the previous acetabular fractures. Furthermore, we used 28-mm-sized femoral head in 17 patients and 36-mm-sized femoral head in 22 patients, which might affect long-term volumetric wear rate. For detecting osteolysis or loosening, CT scans are more sensitive than plain radiograph [21, 22]. Only patients who agreed to CT scans were included in the study and, thus, might not represent the entire population. Nevertheless, we did not find any questionable osteolytic lesions among patients who agreed to have CT scans performed. Despite these limitations, the findings are of value, because this study includes consecutive patients with the same diagnosis and treated with the same implants by a single surgeon at a single institution.

Young patients tend to have higher activity levels than older patients. Although the majority of our patients continued to participate in high-demand activities, acetabular bone deficiency and high activity level did not affect the longevity of the prosthesis. We believe that several factors were responsible: hemispherical acetabular cup insertion with press-fit fixation technique and cementless grit blasted tapered wedge stem [23] and the strong trabecular bone in young patients. A cohort of low BMI also seems to contribute to the good results. The average BMI of the cohort was of 23.4 kg/m^2 (range 19–30.8 kg/m^2). Results may differ in heavier patients. Adequate management of previous acetabular fractures with secure fracture fixation and proper bone grafting were also important factors leading to improved outcomes [24]. Initial fracture patterns and degree of bone defects in the acetabular side can also affect prosthetic longevity. Interestingly, data from this study are contradictory to published data [25, 26]. Zhang et al. had reported 93% overall survival rate of acetabular component at a mean follow-up of 7 years. They reported more acetabular defects and observed more patients with associated fractures patterns (60%) compare to this study (20.5%).

Previously, cement fixation was preferred in the earlier studies of THA after acetabular fractures; however, poor results and high complication rates in the acetabular side have been reported [1, 27]. Recent studies showed that the cementless component was durably fixed even in young, active patients after acetabular fracture [24, 26, 28]. However, a high wear rate of conventional PE and subsequent osteolysis are outstanding concerns [3]. Increased activity in younger patients is presumed to result in increased PE wear. Our findings are similar to wear rates reported in the literature at long-term follow-up for other HXLPE bearing in younger, active patients with other disease and conditions [4, 30–33].

Alternative bearing surfaces are very attractive because of the reduced wear rate and osteolysis [4, 7, 33]. The results of THA with metal-on-metal bearings have revealed very low rates of wear. However, there have been reports of early periprosthetic osteolysis and loosening related to delayed hypersensitivity [34–36]. In spite of the tribological evolution of ceramics, there are still potential problems related with ceramic bearings [37–39]. Our results are consistent with those in other studies of alternative bearings for young patients at a minimum 5-year follow-up without any adverse effects from alternative bearings such as squeaking, ceramic fracture, or hypersensitivity reaction. Periprosthetic osteolysis was not observed in our study.

Conclusion

In conclusion, while the long-term effects of the PE particles from HXLPE remain unknown, the survivorship of implants and wear data in this study at a minimum of 5 years for high-risk population of the previous acetabular fracture are promising. We believe that our encouraging results support the continued use of HXLPE in patients after acetabular fracture without any of the issues associated with a hard-on-hard-bearing couple.

Author Contributions BWM and KJL conceived the study, and participated in its design and coordination. BWM and KJL performed the operation. KCB and CHC collected and analyzed the data. ESS, KJL, and SWL contributed to methodology, supervision, validation, and writing of the original draft. All authors interpreted the data and participated in drafting the text and tables. All authors read and approved the final manuscript.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Ethics Approval This study was approved by institutional review board of Keimyung University Dongsan Hospital (approval number 2018-02-014).

Informed Consent Not applicable.

Availability of Data and Material All the data generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

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