CLINICAL ARTICLE

Comparison of Tri-Lock Bone Preservation Stem and the Conventional Standard Corail Stem in Primary Total Hip Arthroplasty

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Objective: To compare the clinical and radiographic outcomes between the Tri-Lock Bone Preservation Stem (BPS) and the conventional standard Corail stem in primary total hip arthroplasty (THA).

Methods: From March 2012 to May 2014, we retrospectively reviewed 84 patients (104 hips) who received Tri-Lock (BPS) and 84 patients (115 hips) who received conventional standard Corail stem in THA. Their mean ages were 53.12 ± 2.32 years and 52.00 ± 2.11 years, respectively. The clinical outcomes were assessed by Western Ontario and McMaster University Osteoarthritis Index (WOMAC), Pain Visual Analogue Scale (VAS) and Harris Hip Score (HHS). The radiological outcomes were evaluated by the radiological examination. Accordingly, Intraoperative and postoperative complications were observed as well.

Results: The mean follow-up time was 48.23 ± 2.91 months in the Tri-Lock (BPS) group and 49.11 ± 2.11 months in the Corail group, respectively. The bleeding volumes in two groups were comparable (169.22 ± 58.11 mL *vs* 179.30 ± 59.14 mL, $P = 0.003$), with more bleeding volume in Corail group patients, while no statistically significance with respect to operation time was observed (65.41 ± 6.24 min *vs* 63.99 ± 6.33 min, $P = 0.567$). The rates of intraoperative fracture was 8% for the Corail group while 1% for the Tri-Lock (BPS) group (8% *vs* 1%, $P = 0.030$). At final follow-up, no statistical differences in regard to HHS, WOMAC, and Pain VAS were revealed between the two groups ($P > 0.05$). The rate of thigh pain was higher in Corail group than in Tri-lock (BPS) group (5% *vs* 0%, $P = 0.043$). However, incidence of stress shielding in grade 1 was higher in Tri-Lock (BPS) than in the Corail group (76% *vs* 23%, $P < 0.01$), while those in grade 2 and 3 were lower compared to the Corail stem (15% *vs* 28%, $P < 0.01$; 9% *vs* 16%, $P = 0.008$, respectively). Intriguingly, other assessments in relation to radiographic outcomes and postoperative complications were not comparable between the two groups. The Kaplan–Meier survival rate (revision surgery performed for any reason was defined as the end point) was similar between the two groups ($P = 0.57$), with 98.8% (95% confidence interval, 92.3%–100%) in Tri-lock (BPS) group and 97.6% (95% confidence interval, 94.6%–100%) in Corail group.

Conclusions: The Tri-Lock (BPS) has similar clinic performances compared to the Corail stem. Furthermore, the Tri-lock (BPS) stem has some advantages in achieving lower incidence of thigh pain, stress shielding and intra-operative fracture. Therefore, we recommend the Tri-lock (BPS) stem as a good alternative in primary total hip arthroplasty, especially taking into account patient factors, including bone deficiency and convenience of extraction of the stem in hip revision.

Key words: Conventional standard stem; Primary; Short Stem; Total hip arthroplasty

Introduction

THA is continually thought as one of the most successful procedures to restore hip joint function for the patients with advanced joint degeneration[1]. However, aseptic loosening of prosthesis after THA has been widely reported, and it is demonstrated to be correlated with the precedent prosthesis design and the so-called first-generation bone cementing technique. To solve these problems,

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surgeons and engineers strive to improve the design of the stem and have developed a multitude of novel methods to promote biological osseo-integration. Cementless femoral prosthesis, a novel strategy, subsequently emerged in this circumstance and has presently achieved excellent clinical outcomes in THA due to its good bony ingrowth, primary stable compression, as well as high long-term survival rate[2–4]. 4. A number of published studies have reported the overall survivorship of several standard-length tapered femoral components to be ranged from 94% to 100% at up to 20 years' follow-up[5–9].

The Corail stem (Johnson & Johnson, Warsaw, IN, USA) is a cementless, tapered, fully hydroxyapatite-coated titanium femoral component[10]. It was first introduced in 1986 which then gradually became the most common used conventional standard length stem in THA surgeries[11]. In this prosthesis the initial stability depends on its special designs in which the metaphyseal fixation is available. It has a quadrangular cross-section, the proximal portion of the Corail is flared in both coronal and sagittal planes in order to facilitate stable fixation in the proximal femur[12]. While the distal part of the stem was tapered to avoid blocking of the medullary canal, which might distribute the stress subsequently[13]. The surface of the stem is extensively coated with calcium hydroxyapatite with a thickness of 150 μm in order to achieve the best optimal osseo-integration. To date, majority of studies have demonstrated that the Corail stem has excellent performance, with a survival rate of 96.3% even after a 23 year follow-up[10].

However, the lifespan of the cementless prosthesis is not without restrictions, revision surgery may be inevitable in latter life, especially for younger patients[14]. As we know, the native bone stock after the primary THA is a vital factor for subsequent success of revision surgery[15].However, removing the conventional standard length cementless stem is arduous in revision surgery due to its excellent osseo-integration. Therefore, extended great trochanter osteotomy was often performed in this situation, which may predispose the patient to sustain infection, bigger surgical trauma, intraoperational bleeding, longer surgical time and sever host bone losses[16]. Furthermore, nonunion may also existed in some patients, which may ultimately result in revision failure[17].

Therefore, a short cementless stem was designed for these young or active middle-aged patients in recent years. The short cementless femoral stem has several advantages in primary hip arthroplasty, including excellent bony ingrowth, decreased proximal bone resorption, and lower incidence of thigh pain[18]. Furthermore, the short stem can be easily inserted by small incision and less invasive surgery, consuequently contributing to the rapid postoperative recovery of the patients[19] . Besides, owing to the higher femoral neck osteotomized to preserve more proximal bone, the standard-length cementless femoral stem can acquire initial stability in hip revision, instead of the revision stems, which may simplify the operation process and save the cost of patients[20, 21].

Compared to the aforementioned short stem (Tri-lock), Tri-lock (BPS) has significantly shorter length and shape as well as elavated routhness of surface coating of Gription[22]. The merits of the Tri-lock (BPS) are as follows: (i) it has reduced the width and length of its distal stem, which can subsequently reserve the bone volume to the biggest extent and provide adequate cortical contact to the DORR A femur; (ii) the inward shoulder of the stem can protect the greater trochanter when expanding the femoral cavity and implanting the stem, making it a minimal invasive surgery; (iii) the curved distal part of the stem allows multiple surgical approaches to be available, which can reduce damages to the soft tissue; (iv) optimized neck design reduces the collision incidence and maximizes the range of mobility; and (v) Gription porous coatings over the proximal part offered extra stability which can effectively diminish micro-mobility of the prosthesis. Several studies have demonstrated that the Tri-Lock femoral stem has excellent clinical results and superior survivor rate even in more than 15 years' follow-ups[23, 24]. While there only two researches reported the stable fixation and satisfactory clinic outcome of the Tri-lock (BPS) with 4–7 years follow-up in THA[25, 26]. Furthermore, currently there are no published studies directly comparing the clinical outcome and survivor rate of the Tri-lock (BPS) to the conventional standard stem Corail, which was proved to have excellent clinic outcome in THA[27–29] . Whether the Tri-lock (BPS) has some superiority with respect to reducing perioperative/posoperative complications compared to the Corail group is also not known.

Therefore, the purposes of this study includes: (i) comparison of the early clinical outcomes between the Tri-lock (BPS) and the Corail stem; (ii) comparison of the intraoperative results using the Tri-lock (BPS) and the Corail stem in THA; (iii) comparison of the postoperative complication using the Tri-lock (BPS) and the Corail stem in THA; (iv) comparison of the radiographic analysis of the Tri-lock (BPS) and the Corail stem in THA; and (v) comparison of the survival rate of the Tri-lock (BPS) and the Corail stem in THA.

Materials and Methods

Inclusion and Exclusion Criteria

The inclusion criterion were as follows: (i) patients were diagnosed as Avascular necrosis of femoral head, hip joint osteoarthritis, femoral neck fracture, Rheumatoid arthritis, and developmental dysplasia of the hip (DDH) with failed conservative treatment, which had indication for THA with no surgical contraindication; (ii) the patients received THA using Corail or Tri-lock (BPS) components; (iii) the related follow-up outcomes of patients were comprehensively recorded and compared; and (iv) It is the retrospective study. The excluding criterions were: (i) no surgical indication or contraindication in pre-operative examination; (ii) proximal

femur skeletal dysplasia with stenosis of the medullary space; and (iii) which were revised cases.

Patient Selection

This study is a retrospective research, which was approved by institutional review board. Between March 2012 and May 2014, we respectively identified 84 patients (104 hips) who underwent THA with Tri-lock (BPS) stem (Depuy, Johnson & Johnson, Warsaw, IN, USA) and the 84 patients (115 hips) who underwent THA with Corail stem (Depuy, Johnson & Johnson, Warsaw, IN, USA) by simple randomization. In addition, the demographics and clinical profiles between the two groups were matched (Table 1).

Surgical Technique

Anesthesia and Position

Before the surgery, module measurements were taken, according to manufacture protocols, to assess the plane of osteotomy and the size of the stem. All patients were treated with general anesthesia or continuous epidural anesthesia. The surgery was performed in the lateral decubitus position.

Approach and Exposure

All operation was performed through modified Kocher-Langenbeck posterolateral approach. After splitting the gluteus maximus muscle fibers, the short external circumflex muscles were exposed and cut off. Subsequently, the hip joint was posteriorly dislocated.

Resection and Preparation

With a pendulum saw, the femoral head was resected at an appropriate distance above the lesser trochanter according to the preoperative template measurement. Subsequently, the acetabular and femoral medullary cavity was reamed to an appropriate size. Notably, the initial stability of the acetabulum and femur prostheses must be acquired.

Placement of Prosthesis

The acetabular prostheses were used with Pinnacle component system (Depuy, Johnson & Johnson, Warsaw, IN, USA), which were high-edge polyethylene/ceramics liner or ceramics/metal head, respectively. The femoral prostheses were used with the Corail or Tri-lock (BPS).

Postoperative Reconstruction

After operation, the two-generation cephalosporins were administered routinely for 3 days, radiographs were taken to assess if the prosthesis was in good location and alignment. The patients were allowed to bear weight with crutches on the second day after surgery. Rivaroxaban, accompanied with functional exercise, were also prescribed for deep venous thrombosis prevention.

Clinical Assessment

The clinical outcomes of the two stem were followed and recorded at pre-operation, 3 month, 12 month, 12 months and then 2 yearly after surgery until the last follow-up. The WOMAC, PainVAS (mapping of the pain) and HHS were applied to assess the outcomes of the two stems. Meanwhile, operation time, intra-operative bleeding volume and complications occurred during surgery and post-operation were also retrieved accordingly.

Harris Hip Score (HHS)

The HHS was used to evaluate postoperative recovery of hip function in an adult population. The HHS score system mainly includes four aspects as pain, function, absence of deformity, and range of motion. The score standard had a maximum of 100 points (best possible outcome). A total score <70 is considered a poor score, 70–80 fair, 80–90 good and 90–100 excellent.

Western Ontario and McMaster University Osteoarthritis Index (WOMAC Index)

The WOMAC index was used to evaluate the patients with hip osteoarthritis[30]. It can be used to monitor the postoperative functional recovery of hip. The system mainly includes

TABLE 1 Demographic data of two stem groups

Parameters	Trilock-BPS	Corail	*P* value
Number of patients(hips)	84 (104)	84 (115)	
Male:female	35:49	41:43	0.352
Mean age in years	53.12 ± 2.32	52.00 ± 2.11	0.654
Mean body mass index(kg/m)	25.16 ± 2.20	24.34 ± 1.72	0.768
Diagnosis(patients)			
Osteoarthritis	12 (14%)	10(12%)	0.647
Avascular necrosis	25 (30%)	23 (27%)	0.733
Femoral neck fracture	9 (11%)	13 (16%)	0.360
Rheumatoid arthritis	12 (14%)	18 (21%)	0.227
DDH	26 (31%)	20(24%)	0.299
Dorr A/B/C	53/18/13	49/20/15	0.071
Duration of follow-up(MONTHS)	48.23 ± 2.91	49.11 ± 2.11	-

24 parameters, with the highest score to be totaled 96 points. The minimum total score of 0 indicates the best state of health in pain, stiffness and physical function. Accordingly, the maximum total score of 96 indicates the worst state of health.

Pain Visual Analogue Scale (VAS)

The pain VAS is a commonly used quantitative pain score, which is sensitive and comparable. Drawing a 10cm line on the paper, one end of the line is 0, indicating no pain; the other end is 10, indicating severe pain; and the middle part indicates varying degrees of pain. Patients mark points denote the intensity of their pain, in which 0 indicate painless,1–3 points indicate mild and bearable pain, 4–6 points indicate that the pain affects sleep, but the patient can still bear it.7–10 points indicate that patients have increasingly intense, unbearable pain which affect appetite and sleep.

Radiographic Evaluation

Radiographs of standard pelvis were utilized to evaluate if prosthesis subsidence, prosthesis alignment, radiolucent line around the prosthesis, osteolysis, ectopic ossification and stress shielding occurred during the follow-up. Radiographs were examined by two experienced radiologists.

Prosthesis Subsidence

The method to measure the distance of prosthesis subsidence were the distance between the shoulder apex of the stem and the highest site of the great trochanter, if the distance was increased more than 3 mm, prosthesis subsidence should be considered, which may lead to latter stem loosening[31].

Stem Alignment

Stem alignment were measured by the method introduced by Michele Ulivi *et al.*[25], in which the angle were defined by the two intersected center lines of femoral stem and the medullary cavity were showed. Misalignment of the prosthesis may be made if varus–valgus angle was greater than 5°(prosthesis loosening was demonstrated if varus-valgus displacement was greater than 3°).

The Radiolucent Lines

Radiolucent lines were defined as regular, linear, lucent areas surrounding the prosthesis, typically parallel to the implant[32]. It was detected by the method introduced by Gruen[33]. Radiolucent lines mostly remain constant, without any tendency to progress, and reflect a connective tissue layer.

Osteolysis

Osteolysis was defined as the irregularly shaped radiolucent zone along the prosthesis or irregularly demarcated from the surrounding bone[32]. The presence of osteolysis may signify breaks or bone resorption, usually tending to progress.

Ectopic Ossification

Ectopic ossification was evaluated by the classification introduced by Brooker[34]. The Brooker classification divides the extent of Ectopic ossification formation after THA into four classes[35]. Class 1 is described as islands of bone within the soft tissues in the hip. Class 2 includes bone spurs originating from the pelvis or proximal end of the femur, leaving at least 1 cm between opposing bone surfaces. Class 3 consists of bone spurs originating from the pelvis or proximal end of the femur, reducing the space between opposing bone surfaces to less than 1 cm. Class 4 shows apparent bone ankylosis of the hip.

Stress Shielding

Stress shielding was defined as the metal hardness and unphysiological load transmission. Stress shielding was evaluated by the classification introduced by Engh[36]. The first degree indicates slight rounding of the proximal-medial edge of the cut femoral neck[23]; the second degree indicates the loss of medial cortical density at level 1combined with the first degree[23]. The third degree indicates the extensive resorption of the cortical bone extending from level 1 into level 2[23]. The fourth degree indicates extensive resorption of cortical bone beyond levels 1 and 2, extending into the diaphysis[23].

Statistical Analysis

All data were analyzed by SPSS 20.0 (IBM, Armonk, USA), continuous data were presented as mean and standard deviation, independent t test were used to compare the differences between groups; due to the categorical characteristics with respect to thigh pain incidence rate, survival rate, intraoperative fracture occurrence, complication rates and stress-shielding rate, chi-square analysis with Yates' correction was used to compare the statistical differences between groups, P value less than 0.05 was set as statistical significance.

Results

General Results

There were 84 patients in Tri-lock (BPS) group (35 male and 49 female), with average age 53.12 ± 2.32 years and BMI 25.16 ± 2.20 kg/m^2; 84 patients were in Corail group (41 males and 43 females), with average age 52.00 ± 2.11 years and BMI 24.34 ± 1.72 kg/m^2. All patients were followed, the average follow-up time were 48.23 ± 2.91 months in Tri-lock (BPS) and the 49.11 ± 2.11 months in the Corail group, respectively.

Intra-operative Results

The operation time in Tri-lock (BPS) group was 65.41 ± 6.24 min, intra-operative bleeding volume was 169.22 ± 58.11 mL. However, the operation time in Corail group was 63.99 ± 6.33 min and intra-operative bleeding volume was 179.30 ± 59.14 mL. The comparisons of operation time were with no statistical significance (P = 0.567), while

the bleeding volumes in two groups were comparable, with more bleeding volume in Corail group patients ($P = 0.003$). The comparison of intra-operative periprosthetic femoral fracture occurrence rates revealed significant difference between the groups, the occurrence rate was 1% in Tri-lock group and 8% in Corail group ($P = 0.030$). Seven patients with linear fracture occurred at the osteotomy site of the femoral neck, Therefore, steel wire cerclage was undertaken, and latter follow-up validated stable prosthesis with no revision surgery performed subsequently.

Clinical Results

HHS, VAS and WOMAC

The HHS had significantly improved from 45.32 ± 3.42 preoperatively to 93.33 ± 4.11 at final follow-up in Tri-lock (BPS) group ($P < 0.001$) and from the 46.32 ± 3.12 preoperatively to 92.39 ± 5.21 at final follow-up in Corail group ($P < 0.001$). The pain VAS, WOMAC in Tri-lock (BPS) group had significantly improved from 7.22 ± 1.22, 54.04 ± 10.2 preoperatively to 2.13 ± 0.98, 5.58 ± 2.32 at last follow-up ($P < 0.001$) and from the 7.25 ± 2.01, 52.18 ± 9.80 preoperatively to 2.02 ± 1.12, 6.48 ± 2.32 in Corail Group ($P < 0.001$), respectively. However, the comparisons with respect to the mean WOMAC score ($P = 0.76$), Harris Hip Score ($P = 0.98$), and mean pain VAS ($P = 0.38$) at final follow-up were not comparable, indicating no significant differences between the two groups (Table 2).

Radiographic Results

In terms of comparison of the subsidence, the position of the femoral component, ectopic ossification, radiolucent line and osteolysis, there was no significant difference between the two groups. However, there was significant difference between the two stems in respect to the stress shielding (Table 3).

Prosthesis Subsidence and Stem Alignment

No occurrences of prosthesis subsidence and loosening were found during follow-up period, all patients achieved stable bony ingrowth (Figs 1 and 2). In Tri-lock (BPS) group, 74 patients (88%) were in neutral alignment, eight patients (10%) were in varus alignment, and two patients (2%) were in valgus alignment. In the Corail group, 71 patients (85%) were in neutral position of its femoral stem, 10 patients (12%) were in varus position, and three patients (3%) were in valgus position. There was no significant difference between the two groups regarding the stem alignment ($P = 0.50$, $P = 0.61$, $P = 0.65$, respectively).

The Radiolucent Lines, Osteolysis and Ectopic Ossification

In the Corail group, three patients (3%) detected a radiolucent line, with its width less than 1mm in the region I and VII, while the radiolucent line area was not expanded during follow-up intervals, without prosthesis loosening. However, only one case (1%) in Tri-lock(BPS) group developed radiolucent line of <1 mm in GruenIand VII region. In term of the osteolysis, no patients were observed at the final follow-up between the two groups. Four Patients (5%) in Tri-lock (BPS) group and three patients (3%) in Corail group showed the ectopic ossification. There was no significant difference regarding radiolucent lines ($P = 0.31$) and Ectopic ossification ($P = 0.69$) in the final follow-up between the groups (Table 3).

Stress-shielding

Sixty-three patients (76%) detected stress shielding in grade 1 in the Tri-lock (BPS) group and 23 patients (27%) in Corail group ($P < 0.01$). Fifteen patients (15%) detected stress shielding in grade two in the Tri-lock (BPS) group and 48 patients (57%) in Corail group ($P < 0.01$). Six patients (9%) detected stress shielding in grade 3 in Tri-lock (BPS) group and 13 patients (16%) in Corail group ($P < 0.01$). There was significant difference regarding stress shielding grades 1, 2 and 3 ($P = 0.640$) at the final follow-up between two groups (Table 3).

Revisions and Kaplan–Meier Survival Rate

In the Corail group, the revision THA were performed for two patients, one patient received the two-stage revision because of prosthetic joint infection while the other was due to Periprosthetic fracture (Vancouver B3). However, only one patient required revision because of recurrent dislocation in the Tri-lock (BPS) group. With revision for any reason as the end point, the Kaplan–Meier survival rate was similar between the two groups ($P = 0.57$), 98.8% (95% confidence interval, 92.3%–100%) in Tri-lock (BPS) group and 97.6% (95% confidence interval, 94.6%–100%) in Corail group.

Complications

Concerning the comparison of the postoperative complication occurrence rates, there were no significant differences between the two groups in Superficial infection, Dislocation Deep venous thrombosis, Pneumonia, Limp and Sciatic nerve numbness (Table 2). However, four (5%) patients in Corail group complained of thigh pain while no patients in Tri-lock (BPS) group did, and the thigh pain occurrence was comparable with statistical significance between the two groups ($P = 0.043$).

Discussion

In this study, we retrospectively analyzed the clinical and radiographic outcomes of Tri-lock (BPS) and Corail stem in THA, and no statistical significance was found with respect to HHS, pain VAS and WOMAC in a 4-year follow-up, and no complications related to prosthesis were found. Furthermore, Tri-lock (BPS) stem had some advantages including reduction of thigh pain, stress shielding, intra-operative fracture occurrence and bleeding volume, as well as bone reservation in the proximal part, during surgery when compared with conventional standard Corail stem.

TABLE 2 Clinical results

parameters	Trilock-BPS	Corail	*P* value
Mean Harris hip score			
Preope	45.32 ± 3.42	46.32 ± 3.12	0.163
Final FU	93.33 ± 4.11	92.39 ± 5.21	0.987
Mean total WOMAC score			
Preope	54.04 ± 10.2	52.18 ± 9.80	0.668
Final FU	5.58 ± 2.32	6.48 ± 2.32	0.762
Pain VAS			
Preope	7.22 ± 1.22	7.25 ± 2.01	0.795
Final FU	2.13 ± 0.98	2.02 ± 1.12	0.382
Average operative time(min)	64.41 ± 6.24	63.99 ± 6.33	0.567
Average estimated blood loss (mL)	169.22 ± 58.11	179.30 ± 59.14	0.003
Periprosthetic femoral fracture	1 (1%)	7 (8%)	0.030
Thigh pain(*n*)	0	4	0.043
Superficial infection	0	3	0.081
Dislocation	1	2	0.056
Deep venous thrombosis	0	2	0.155
Pneumonia	3	2	0.065
Limp	2	0	0.155
Sciatic nerve numbness	0	1	0.316

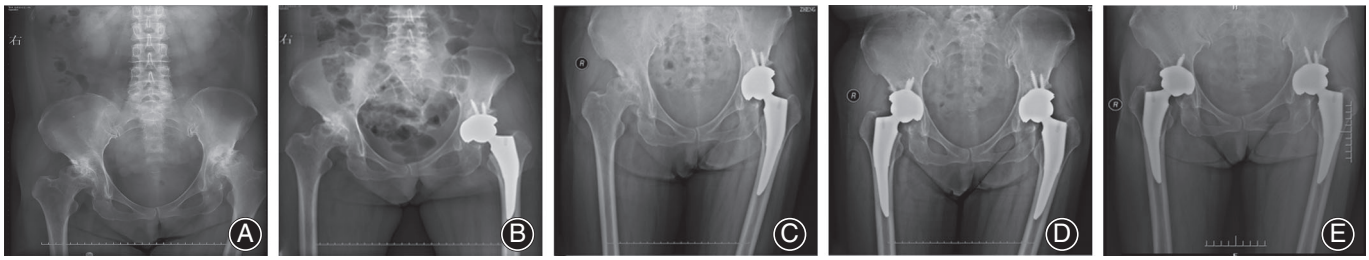

Fig. 1 (A) The preoperative radiograph of the hip of a 48-year-old male patient who had bilateral DDH. (B-E) The radiograph at 3, 12, 24, 48 months in the left hip after implantation of Tri-lock BPS stem showed solid fixation in a satisfactory position, respectively.

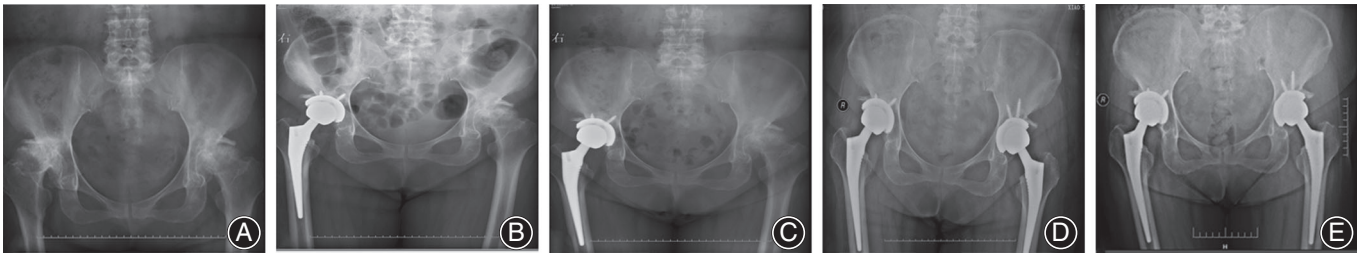

Fig. 2 (A) The preoperative radiograph of the hip of a 65-year-old male patient who had bilateral DDH. (B-E) The radiograph at 3, 12, 24, 48 months in the right hip after implantation of Corail stem showed solid fixation in a satisfactory position, respectively.

Similar Clinical Outcome and Survival Rate Between Two Stems at Final Follow-up

The Tri-lock (BPS) is more suitable for young and middle-aged adult as it has reserved more bone volume compared to its last-generation of predecessor Tri-lock. At present, the good long-term survival rate and excellent clinic outcome of the Tri-Lock stem have been demonstrated[23, 37]. Nevertheless, reports about Tri-lock (BPS) stem were rare, especially the studies directly comparing the conventional standard Corail to the Tri-lock (BPS). Hence, we have studied the clinical outcomes by HHS, Pain VAS and WOMAC between the Corail group and the Tri-lock (BPS) group in this study and, as expected, no comparable significance between the two groups was revealed ($P > 0.05$). The efficacy of Tri-lock (BPS) was not lower than that of Corail stem, even the Tri-lock (BPS) had more excellent performance, which are in agreement to previous researches. Tomaszewski *et al.*[38] compared the outcomes of patients who were performed ultra-

TABLE 3 Radiographic final follow-up results of the two stem groups

Parameter	Trilock-BPS	Corail	*P* value
Stem alignment (*n*, %)			
neutral	74 (88%)	71(85%)	0.501
varus	8 (10%)	10 (12%)	0.618
valgus	2 (2%)	3 (3%)	0.650
Aspetic loosing	0	0	-
Subsedence	0	0	-
Osteolysis	0	0	-
Radiolucent line <1 mm	1 (1%)	3 (3%)	0.311
Ectopic ossification	4 (5%)	3 (3%)	0.699
Stress shielding			
Grade 1	63 (76%)	23 (27%)	<0.01
Grade 2	15 (15%)	48 (57%)	<0.01
Grade 3	6 (9%)	13 (16%)	0.008
Grade 4	0	0	-
Survival rate	98.8%	97.6%	0.570

short proxima stem and conventional standard stem, and the patients in the proxima group were demonstrated to have better clinic results and higher life qualities. Klein *et al.*[20] had included 83 patients in a randomized study to compare the collum femoris-preserving Stems with Corail stem in total hip arthroplasty in regard to its clinic efficacy and early-stage stem subsidence character. After a 2 year follow-up, the clinical outcomes were found not to be comparable, with similar migration of the stem but different migration patterns. Furthermore, taking revision for any reason as the end point, the Kaplan–Meier survival rate was similar between the two groups.

Less Intra-operative Periprosthetic Femoral Fracture and Bleeding Volume for the Tri-lock (BPS)

In this study, we also investigated and compared the clinic results in terms of intra-operative bleeding volume, operation time, and intra-operative periprosthetic femoral fracture. Bleeding volume in Tri-Lock (BPS) group was obviously less than that in Corail group, but no differences in operation time were detected. Interestingly, Hochreiter *et al.*[39] had compared 124 patients who were undertaken the short stem with 141 patients who received the conventional straight stem in total hip arthroplasties in terms of intra-operative bleeding volume, postoperative erythrocyte content, operation time, and postoperative complication, and the follow-up results showed that the intra-operative bleeding volume and postoperative transfusion volume were significantly lower in short stem group (1139 *vs* 1358, $P < 0.001$; 8% *vs* 15.6%, $P < 0.001$, respectively), but no measurable differences were clarified in clinic outcomes and operation time. The factors contributed to better performances of the short stem group may be due to its minimally invasive pattern, which may cause less soft tissue damages to implant the femoral stem, prepare more convenient over the femoral part, and reserve more bone volume for potential latter revision surgery in THA[40]. Recently, Migliorini *et al.*[18] published a meta analysis in 2020 about the clinic outcome comparisons between the short stem and the long stem, in which they investigated 2197 THA in 2116 patients with 30.2 months follow-up and found that WOMAC score was higher in short stem group, as well as less bleeding volume. Also, Fractures during operation were a common complication in THA, the occurrence rates were 2.95%–27.8% in different articles[41]. In our study, the fracture incidence was higher in Corail group compared to Tri-lock (BPS) group (8% *vs* 1%, $P < 0.05$). Moli *et al.*[40] had studied 606 patients with THA and compared their fracture rates in short and conventional stem, and found that the fracture rate during surgery was also lower in short stem group (0.4% *vs* 3.1%, $P < 0.05$). Danielle *et al.*[41] had reported the fracture occurrence rates were similar in both Tri-Lock group and allocated group in THA, multiple logistical regression analysis demonstrated that the fracture incidence rate was closely associated with narrowing of the femoral cavity and female gender. Therefore, more min-invasive, less damage to soft tissue, more convenient to operate on and faster rehabilitation were the advantages of the Tri-lock (BPS).

Lower Grade of Stress Shielding for the Tri-lock (BPS) at Final Follow-up

Metal hardness and un-physiological load transmission, namely stress shielding, is important factors in bone remodeling. Undesirable stress-shielding may lead to osteolysis around the prosthesis, which may accelerate aseptic loosening and decrease the long-term survival rate of the prosthesis. Many articles have demonstrated that short stem may decrease the payload of the distal part on femur which makes it better fitted to physical proximal part [42, 43]. In our research, no prosthesis subsidence, loosening, migration, and bony ingrowth were detected by radiological evaluations. Interestingly, the incidence rate of stress-shielding in grade 2, 3 of the Tri-Lock BPS group was apparently lower compared to the Corail group at last follow-up (15% *vs* 57%, 9% *vs* 16%, $P < 0.01$, $P = 0.008$, respectively), while higher in grade 1 than that of the Corial group (76% *vs* 27%, $P < 0.01$), especially in Gruel regions 1 and 7, which was in parallel to a previous report. Hochreiter *et al.*[44] had prospectively investigated the bone mineral density of the femoral remodeling site after THA and they found the increased bone mineral density areas in the short stem group were located in the lateral part (Gruen regions 2 and region 3) and distal part (Gruen region 5), indicating existed lateral payload. These studies further corroborated that restriction of stress-shielding in the short stem can decrease the bone loss around the stem to the lowest extent in the circumstance of not deteriorating the primary stability of the prosthesis.

Lower Occurrence Rate of the Thigh Pain for the Tri-lock (BPS)

Previous studies have reported that the short stem has not anchored to the femur shaft, which may simultaneously decrease the stress-shielding and occurrence of the thigh pain[19]. Additionally, the thigh pain is not a special complication in THA, and, more importantly, it is closely correlated with prognosis of the patients after these surgeries[45]. In our

study, we observed the occurrence of thigh pain was lower in Tri-lock (BPS) group (no patients in Tri-lock (BPS) group and 5% in Corail group). Likewise, Huo *et al.*[46] summarized 6 RCT studies about the incidence of thigh pain between the short stem and conventional stem and found the general incidence of thigh pain was also much lower in short stem group (hazard ratio: 0.1595%, confidence interval: 0.04–0.49, $P = 0.002$), which was similar to our research. Kim *et al.*[12] also had comparatively studied the thigh pain incidence and clinic outcomes in short and ultra-short femoral stem, and their results demonstrated that no incidence of thigh pain occurred with 17 years follow-up, the possible factors related to this phenomenon may be owing to the proximal axial and rotational stability of the femur, as well as no contact between the distal shaft and the femoral cortex.

Limitation

There are also some limitations existed in this research: 1) the patients in this article were a small cluster, which may not represent the whole population, and the follow-up time was not long enough to accurately investigate the long-term results; 2) the long-term survival rate of the two prosthesis was only assessed by X-ray of the pelvis, not the RSA to accurately study the results; 3) regarding periprosthetic bone remodeling process, dual-energy X-ray was not utilized to precisely measure the bone density around the prosthesis; 4) its retrospective nature may inherently cause some biases in patients collection, which are very common and inevitable in all retrospective articles.

Conclusion

Our results demonstrated that the Tri-lock (BPS) has similar performances in clinic outcomes compared to the Corail stem. Furthermore, the Tri-lock (BPS) stem has lower incidence of thigh pain, stress shielding and intra-operative fracture. Taking into account of patients factors, including bone deficiency and convenience of extraction of the stem in hip revision, we recommend the Tri-lock (BPS) stem as a good alternative in primary total hip arthroplasty.

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