


## CLINICAL ARTICLE

# Mid- to Long-Term Outcomes of Cementless Modular, Fluted, Tapered Stem for Massive Femoral Bone Loss in Revision Total Hip Arthroplasty

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**Objective:** To evaluate mid- to long-term results of revision total hip arthroplasty for massive femoral bone loss using a cementless modular, fluted, tapered stem.

**Methods:** This is a retrospective study performed at a single hospital. During the period of January 2007 to January 2015, 33 patients (34 hips) underwent primary revision surgery with cementless modular, fluted, tapered stems due to femoral bone loss. Sixteen men and 17 women were included in the study, with an average age of  $63.9 \pm 11.7$  years (range, 27 to 88 years). Operative data including operative duration, length of incision, drainage volume and duration, blood loss and transfusion, cases of bone graft and extended trochanteric osteotomy were recorded. Clinical evaluation was performed using Harris hip score (HHS), visual analogue scale (VAS), and patients' satisfaction. Radiographic data including femoral stem fixation, subsidence, integrin of allograft bone, and leg length discrepancy were assessed. Complications and survivorship were evaluated using Kaplan–Meier survival rate.

**Results:** The mean follow-up was  $9.1 \pm 2.5$  years (range, 5–13 years). The Harris hip score was  $43.6 \pm 11.5$  preoperatively and maintained at  $86.5 \pm 6.6$  at the time of latest follow-up ( $P < 0.05$ ). The X-ray showed bone ingrowth fixation in 30 hips (88%), fibrous stable fixation in three hips (9%), and instability in one hip (3%). The average stem subsidence was  $3.9 \pm 2.2$  mm (range, 1 to 10 mm). The mean difference in leg length in our study was  $3.3 \pm 2.7$  mm (range, 0 to 10 mm), and the leg length discrepancy in 28 (82%) patients was within 5 mm. No case of junction fracture was observed. Seven (21%) intraoperative fractures occurred in our study. Three (9%) cases with infection were observed after revision. Six (18%) patients had lower limb vein thrombosis. The survivorship of prostheses with revision for any reason was 95% (95% CI, 12.0 to 13.0) at the 10-year follow-up. Three (9%) re-revisions were needed, including one for aseptic loosening, one for dislocation, and one for infection.

**Conclusion:** The mid- to long-term results of revision total hip arthroplasty with the cementless modular, fluted, tapered stems are encouraging for massive femoral bone loss.

**Key words:** Bone loss; Revision; Total hip arthroplasty

## Introduction

Over the past few decades, the number of revision total hip arthroplasty (RTHA) procedures performed has

gradually increased following the large cohort of total hip arthroplasties (THAs)<sup>1</sup>. Furthermore, it has been predicted that the demand for RTHAs will be dramatically amplified

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by over 137% worldwide by 2030<sup>2-5</sup>. Aseptic loosening and peri-prosthetic fracture are two common causes of failed THA<sup>6</sup>, which are triggered by the accumulation of wear particles at the peri-prosthesis area for initiation of osteolysis<sup>7</sup>. Sustained osteolysis around the implant triggers massive bone loss and therefore fails to compress and solidly fix the implant<sup>8</sup>. Bone loss remains one of the biggest technical challenges in RTHA. In such a situation, RTHA is required to reconstruct damaged bone and restore the bone stock.

A variety of strategies have been applied to treat femoral bone loss in RTHA. Long cemented stems for aseptic loosening in elderly patients permit early weight bearing and show promising clinical and radiographic outcomes<sup>9</sup>. Long tapered hydroxyapatite-coated stems can provide stable fixation, bone integration, and reduce stress shielding. However, these stems are suitable for patients with Paprosky I and II defects who had good proximal femoral bone stock<sup>10</sup>. In addition, cylindrical stems have been considered as the standard used in revision with femoral bone defects for many years, while increased failure of ingrowth and loosening has been commonly reported<sup>11</sup>. Moreover, monoblock tapered stems were involved in regeneration of proximal femoral bone following revision THA and reported satisfactory clinical outcomes<sup>12, 13</sup>. Also, impaction bone grafting is another strategy to reliably restore bone loss in RTHA<sup>14</sup>. Nevertheless, the effect of these reconstruction techniques is limited in massive femoral bone defects or unsatisfactory for long-term results<sup>15-17</sup>.

Cementless modular, fluted, tapered stems are another option for massive femoral bone defects in RTHA<sup>18</sup> and exhibit several beneficial characteristics. For example, the tapered distal design is easier to engage a short isthmus segment compared with cylindrical distal geometry<sup>11</sup>; moreover, the modular design allows adjustment of the leg length, anteversion and offset to optimize stability and reduce the potential risk of dislocation for specific patients<sup>19</sup>. Furthermore, the grit-blasted titanium surface facilitates bone growth and attenuates thigh pain and stress shielding<sup>20</sup>.

However, concerns about junctional fractures of the modular stem have been raised and reported by a few authors<sup>21, 22</sup>. Several studies of RTHA with modular, fluted, tapered stems obtained good results at short- to mid-term follow-up<sup>23-25</sup>. However, few reports of the long-term results of these prostheses are available, and survivorship of the junction of the modular stem is worth further investigation.

Therefore, in this study we followed up patients who underwent RTHA using cementless modular, fluted, tapered stem for femoral bone loss. The purpose of this retrospective study was: (i) to evaluate the mid- to long-term clinical and radiographic results of modular, fluted, tapered, stem in massive bone defect RTHA; (ii) to determine the complications in these complex patients with massive bone loss; and (iii) to investigate the long-term survivorship of the junction of the modular stem.

## Materials and Methods

### Inclusion and Exclusion Criteria

Inclusion criteria were: (i) revision THA with bony defects of the proximal femur classified as Paprosky<sup>26</sup> type II-IV or Vancouver<sup>27</sup> type B2-B3; (ii) patients who underwent primary RTHA with femoral bone loss using LINK MP cementless modular, fluted, tapered stem (Waldemar Link, Hamburg, Germany); (iii) all revision-bearing surfaces were ceramic-on-ceramic (CoC); and (iv) all RTHAs were performed by one single, experienced orthopaedic surgeon.

Exclusion criteria were: (i) all kinds of tumors or secondary neoplasia diseases; (ii) patients with prosthetic joint infection (PJI); (iii) patients with severe underlying diseases or cardiopulmonary dysfunction graded as New York Heart Association (NYHA) classification IV and American Society of Anaesthesiologists (ASA) classification IV; and (iv) patients who underwent re-revision THA.

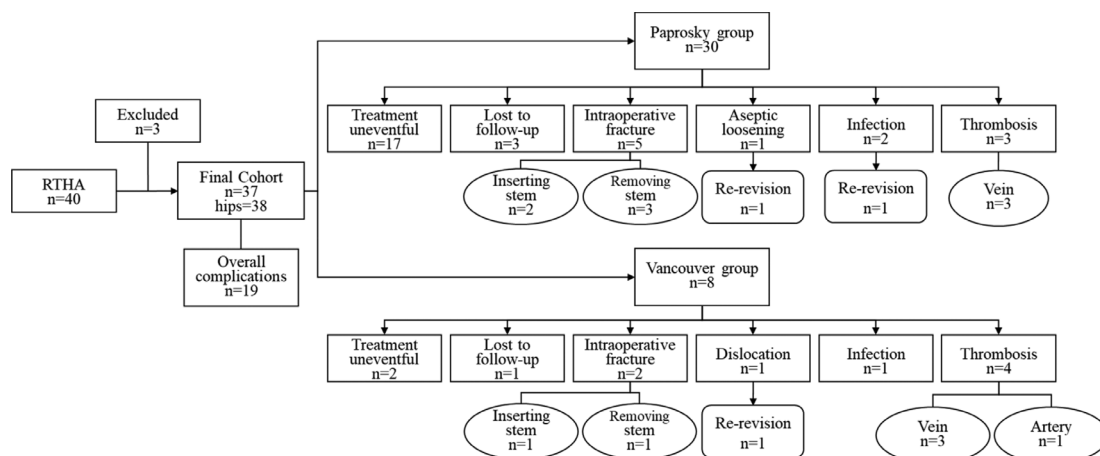


Fig. 1 Flowchart of patient selection in the present study.

### General Characteristics of Participants

This retrospective study was performed with the approval of the institutional ethics committee. From January 2007 to January 2015, 40 patients underwent RHTA with femoral bone defects. After application of exclusion criteria, 37 patients were eligible for review. However, four patients were lost to follow-up within 5 years after surgery. Therefore, we ultimately enrolled 33 consecutive patients (34 hips) with femoral bone defects after primary THA (Fig. 1).

### Operative Techniques

Step 1: All operations were performed using general anesthesia. The patient was placed in the lateral position with adduction and internal rotation of the affected hip joint. The perineum was protected using non-woven fabric. The skin of the whole leg and feet was disinfected and sterile drapes were placed on the operation side.

Step 2: The posterolateral approach was performed along the previous incision in all operations. We sequentially cut the skin, subcutaneous tissue, incised the fascia lata and bluntly dissected the gluteus maximus. Then, the gluteus medius was identified and forward retracted, followed by abduction and external rotation of the hip to expose the gluteus minimus and piriformis. The tendon of piriformis was incised after being marked by suture. Next, we dissected short external rotators and hip capsule to expose the artificial joint. Finally, we dislocated the hip joint by flexion, adduction, and internal rotation of the hip.

Step 3: Then, the loosened implant was extracted. Damaged bone, callus, and scar tissues could be observed. The residual tissues in the femoral canal and acetabulum were debrided completely. At the same time, the removed tissue was tested for pathology and bacteriology. The extended trochanteric osteotomy (ETO) was performed in situ<sup>28</sup>, such as severe femoral prosthesis subsidence or extensive femoral proximal osteolysis to avoid trochanteric fracture and eccentric reaming.

Step 4: After revision of the acetabulum, we prepared the femoral canal for implantation using hand reaming. Then, we applied trial segments in a satisfactory position to optimize the leg length, anteversion, and soft tissue tension. Finally, the prosthesis was implanted.

Step 5: Hip joint activities were tested again; if there was no risk for dislocation, the incision was closed and bandaged under pressure. In addition, cerclage wires, structural autografts, or allografts were used for femoral reconstruction.

Surgical diagrams of revision total hip arthroplasty are shown in Fig. 2.

### Rehabilitation

The methods of enhanced recovery after surgery were applied to permit patients to recover faster and more effectively<sup>29</sup>. Tranexamic acid was used before and after surgery to reduce blood loss, and the drainage tube was removed within 48 h after the surgery. Routine anticoagulant therapy was applied for at least 14–35 days to prevent lower limb

deep vein thrombosis (DVT). Physical therapists guided patients to exercise muscle strength and passive knee motion on the same day after surgery. Under the supervision of the physical therapist, they started to exercise actively, stand at the side of the bed, and walk with a walker twice daily for 30 min each time. Full weight-bearing with a walker was required for 6 weeks.

### Clinical and Radiographic Evaluation

#### Massive Femoral Bone Loss Quantification

The quantitative evaluation of femoral bone loss was based on the area of femoral bone loss, quality of remaining support bone stocks, and stability of femoral component. The evaluation was classified as following: mild: minimal proximal metaphyseal bone loss with diaphysis cortical bone intact, and the femoral component is stable; mid: moderate absent proximal metaphyseal bone loss with diaphysis cortical bone intact, and the stem is loose; massive: severe absent proximal metaphyseal bone loss with diaphysis cortical bone absent at different degrees, and the stem is markedly loose.

#### Harris Hip Score (HHS)

The HHS<sup>30</sup> was used to evaluate the function of hip pre- and postoperatively. The HHS evaluation system consists of four parts: pain, function, absence of deformity, and range of motion. The maximum HHS was 100 points (the higher the score, the better the outcome). The clinical significance of these scores was graded as following: <70 poor; 70–80 fair; 80–90 good; and 90–100 excellent.

#### Visual Analogue Scale (VAS)

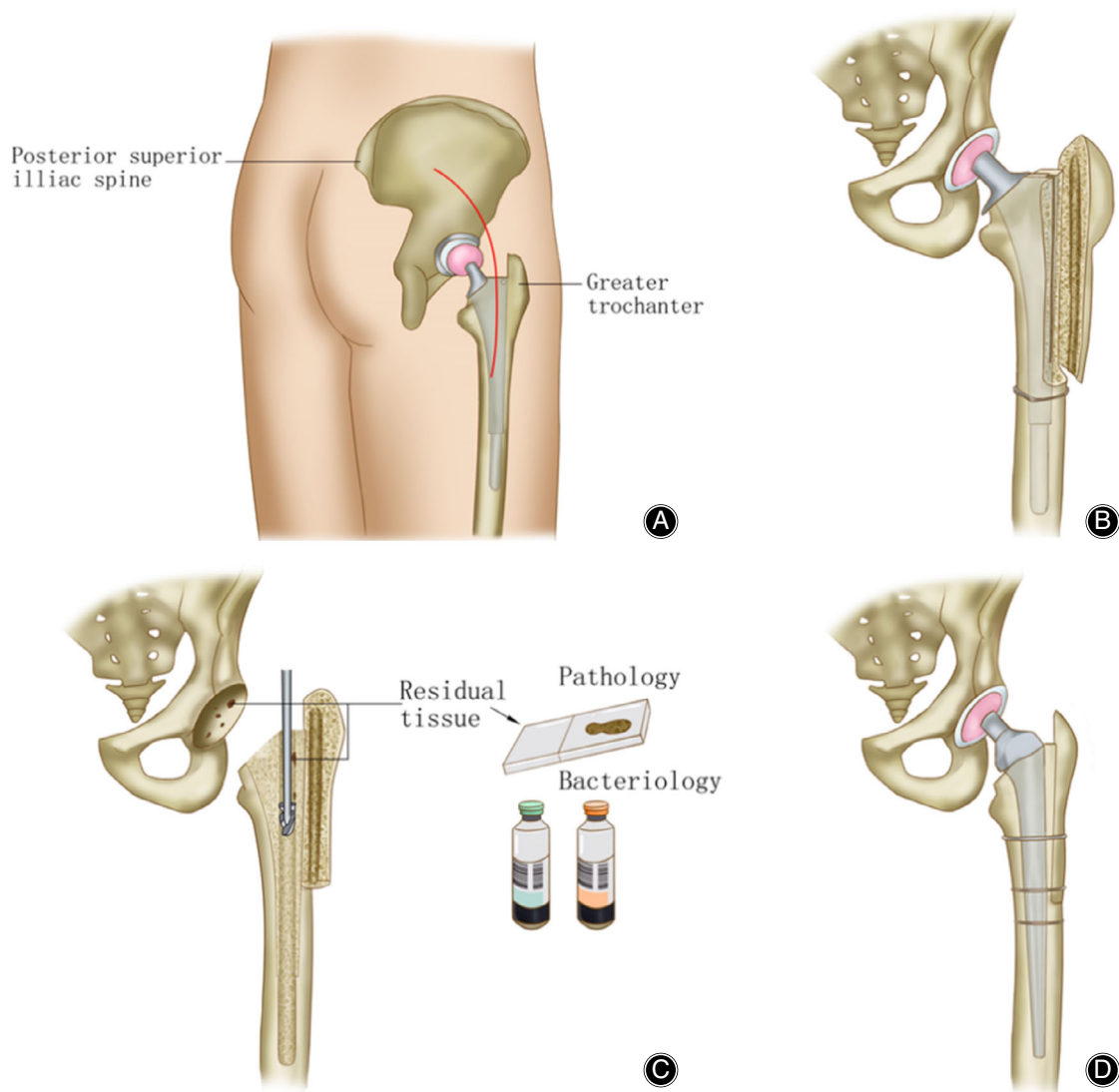
The VAS score<sup>31</sup> was used to evaluate the degree of hip joint pain pre- and postoperatively. The degree of hip joint pain was assessed using a visual analogue graduated scale from 0 to 10 points (no pain to extreme pain). The clinical significance of these scores was graded as following: 0: no pain; 1–3: mild pain, tolerable; 4–6: moderate pain, mild affected sleep, still tolerable; and 7–10: severe, unbearable pain, affected appetite, and unable to sleep.

#### Complications

Major complications including intraoperative fracture, infection, thrombosis, dislocation, ETO non-union, aseptic loosening, peri-prosthesis fracture, and modular junction fracture were recorded. Any re-revisions related to the revision hips were also recorded.

#### Fixation of Femoral Stem

The standard anteroposterior view of the bilateral hip and lateral view of the operative hip were taken for each patient. All imaging data were displayed and measured *via* the picture archiving and communication system (PACS, Neusoft Medical Information System, Shenyang, China). All radiographs were measured by two observers who were blinded to the patients' recovery. The femoral stem fixation was used to



**Fig. 2** Revision total hip arthroplasty surgical diagrams of the key procedure. (A) The posterolateral approach was performed along the previous incision; (B) The utilization of extended trochanteric osteotomy (ETO); (C) The residual tissues were debrided and tested for pathology and bacteriology; (D) The cerclage wires were used for femoral reconstruction.

evaluate the stability of inserted prosthesis. The classification of femoral stem fixation<sup>32</sup> was graded as following: stable: formation of new bone in porous areas with no radiolucent lines; fibrous stable: no progressive subsidence of prosthesis or extensive radiolucent lines; unstable: obvious subsidence and varus of prosthesis with extensive radiolucent lines and sclerosis.

#### *Subsidence of Femoral Stem*

The range of subsidence of the femoral stem was used to evaluate the survivorship of the prosthesis. The subsidence was assessed using the distance from the tip of the greater trochanter to the stem shoulder<sup>33</sup>. The degree of stem subsidence exceeding 5 mm was considered significant<sup>34</sup>.

#### *Stress Shielding*

The stress shielding effect was used to evaluate the bone defect of proximal femur. The stress shielding was assessed by thickness of cortical bone and bone density. It was divided into four levels according to the Engh zones<sup>35</sup>: level 0: no bone absorption was observed; level I: bone absorption was observed in one to four zones; level II: bone absorption was observed in five to seven zones; bone absorption was observed in more than eight zones.

#### *Restoration of Bone and Integrin of Allograft Bone*

The restoration of bone and integrin of allograft bone were used to evaluate the quality of bone reconstruction. Restoration of bone was calculated by the ratio of the width of the

cortical bone to its outside diameters, which was measured at 1 cm distal to the inferior margin of the lesser trochanter<sup>36</sup>. The integrin of allograft bone was judged by the trabeculae between the grafted and host bones<sup>37</sup>.

#### Leg Length Discrepancy

The discrepancy of leg length was used to evaluate the recovery of patients related to back pain and gait correction. The discrepancy was assessed using the perpendicular distance from the tip of the lesser trochanter to the teardrop line. The leg length discrepancy was required to correct to within 10 mm<sup>38</sup>.

#### Statistical Analysis

IBM SPSS 25.0 (International Business Machines, Armonk, New York, USA) was used for statistical analysis. Continuous variable data obeyed a normal distribution, and the mean and standard deviation were determined for each measurement, shown as ( $\bar{x} \pm s$ ). Additionally, the 95% confidence interval, range, and percentage were calculated for partial data. Data between two groups were statistically analyzed with the use of an independent-sample t test. A Kaplan–Meier analysis was used to assess survivorship. *P* values of <0.05 were considered significantly significant.

## Results

#### Demographic Data

There were 17 male and 16 female patients with an average age of  $63.9 \pm 11.7$  years (range, 27 to 88) in this study (Table 1). The primary THA indications included osteoarthritis, femoral head necrosis, femoral neck fracture, developmental dysplasia of the hip (DDH), and ankylosing spondylitis. Among these patients, 27 (79%) were Paprosky types II, III, and IV, and seven (21%) were Vancouver types B2 and B3 (Figs 3 and 4). The mean body mass index (BMI) was  $23.7 \pm 3.7$  kg/m<sup>2</sup> (range, 18 to 31 kg/m<sup>2</sup>). There were four patients lost to follow-up, the follow-up rate was 89.2% (33 patients). The minimum follow-up was 5 years (mean 9.1 years; range, 5 to 13 years). The follow-up of 14 (41%) patients exceeded 10 years.

#### General Results

During surgery, the mean operative duration was  $187.2 \pm 63.9$  min (range, 113–335 min, Table 2). The mean length of incision was  $19.4 \pm 5.2$  cm (range, 10–30 cm). Twenty out of 27 (74%) patients received bone graft in Paprosky group, and all patients in Vancouver group used bone graft. ETO was performed for 10 (37%) patients in Paprosky group (Fig. 5). Moreover, auxiliary fixations, including plates, single cortical screws, or cerclage wires were applied in 10 (37%) and six (86%) cases in Paprosky and Vancouver groups, respectively. After surgery, the drainage volume and duration were recorded. The mean drainage volume was  $164.9 \pm 122$  mL (range, 11–580 mL). The mean drainage duration was  $52.9 \pm 11.4$  h (range, 24–72 h). In addition, the mean hospital stay was  $15.4 \pm 6.2$  days (range, 7–37 days).

**TABLE 1 Demographic data**

Parameter	Value
Age* (year)	63.9 ± 11.7 (range, 27 to 88)
Height* (cm)	161.7 ± 7.9 (range, 140 to 180)
Weight* (kg)	62.0 ± 10.1 (range, 46 to 80)
Body mass index* (kg/m <sup>2</sup> )	23.7 ± 3.7 (range, 18 to 31)
Side† (n = 34)	
Left	18 (53%)
Right	16 (47%)
Sex† (n = 33)	
Female	16 (48%)
Male	17 (52%)
Primary THA indication†	
Osteoarthritis	8 (24%)
Femoral head necrosis	6 (18%)
Femoral neck fracture	10 (29%)
Developmental Dysplasia of the Hip	7 (21%)
Ankylosing spondylitis	2 (6%)
Else‡	1 (3%)
Interval period from THA to RTHA†	9.9 ± 3.3 (range, 2 to 16)
Diagnosis† (n = 34)	
Loosening	27 (79%)
Peri-prosthesis fracture	7 (21%)
Paprosky classification†	
II	7 (21%)
IIIA	11 (31%)
IIIB	7 (21%)
IV	2 (6%)
Vancouver classification	
B2	3 (9%)
B3	4 (12%)
Mean follow-up*	9.1 ± 2.5 (range, 5 to 13)

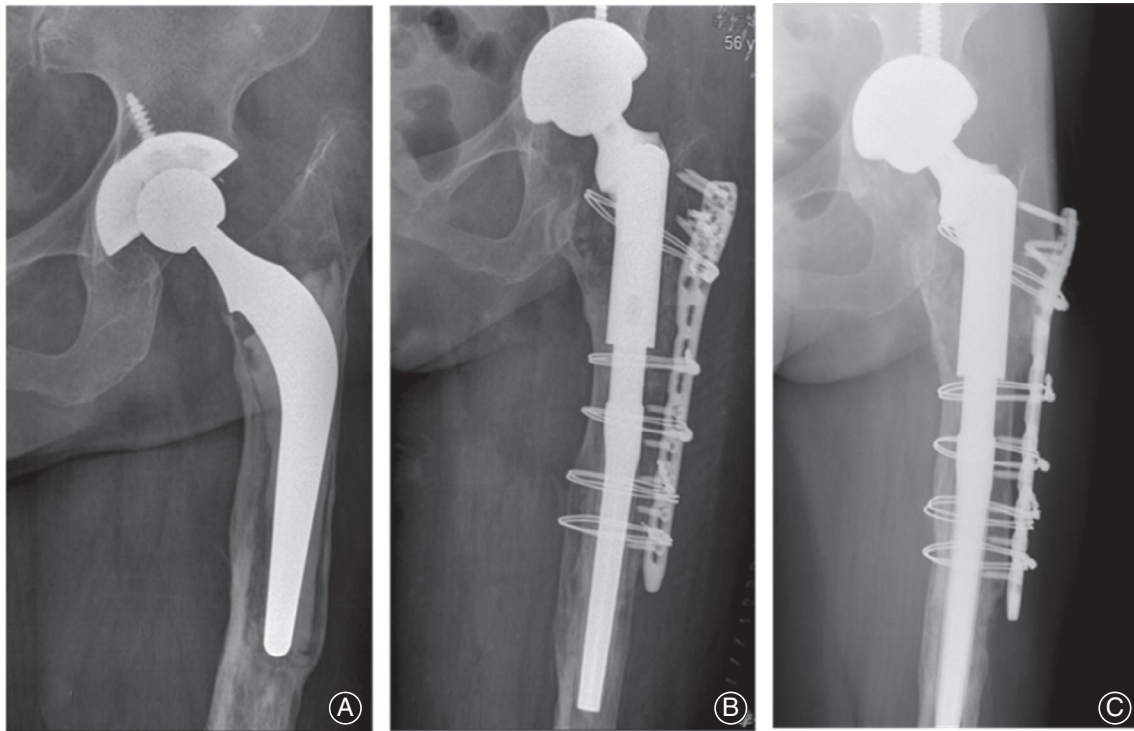
\* The values are given as the mean and the standard deviation, with the range in parentheses.; † The value is given as the number of hips, with the percentage in parentheses.; ‡ Else: acetabulum fracture.

#### Harris Hip Score (HHS)

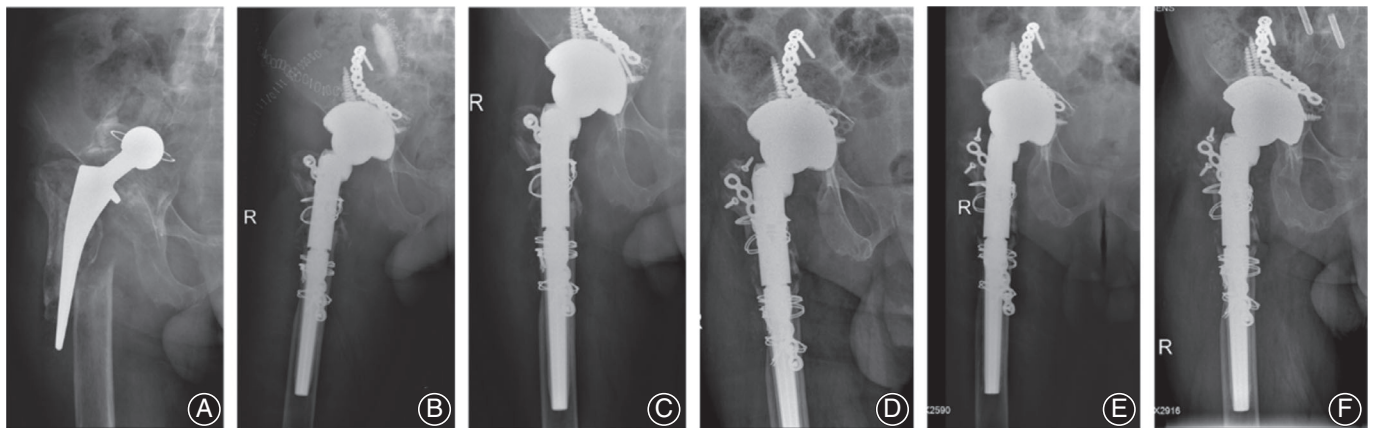
Clinical evaluation showed that the HHS improved significantly from an average of 43.6 points (range, 17 to 67) preoperatively to 86.5 points (range, 67 to 97) at the last follow-up in all patients, which showed a significant difference with a mean HHS improvement of 42.9 (*P* < 0.01) (Table 3). With respect to the comparison of pre- and postoperative HHS between the prosthesis loosening group and peri-prosthesis fracture group by the criteria of Paprosky and Vancouver, we found that the postoperative functional results were similar in patients of both groups.

#### Visual Analogue Scale (VAS)

Consistently, the VAS scores for these patients decreased from a mean preoperative 7.1 points (range, 6 to 9) to 1.1 points (range, 0 to 3) postoperatively, with a mean VAS score decrease of 6.0. There was no significant difference in the mean VAS scores between the Paprosky and Vancouver group.



**Fig. 3** Radiographs of a 56-year-old woman who underwent hip revision 4 years after THA. (A) Radiograph before revision, showing a loosened cemented stem. (B) Postoperative radiograph with the MP Link modular prosthesis. (C) Radiograph at 10 years postoperatively. The patient obtained a good clinical outcome with no subsidence of the stem.



**Fig. 4** Radiographs of a 60-year-old man who underwent hip revision 8 years after THA. (A) Radiograph before revision, showing a peri-prosthesis fracture. (B) Postoperative radiograph with a plate and cerclage wire. (C) Radiograph at 1 year postoperative. (D) Radiograph at 3 years postoperative. (E) Radiograph at 5 years postoperative. (F) Radiograph at 8 years postoperative.

### Satisfaction

Twenty-four (89%) patients in the Paprosky group felt satisfied with the surgery, while all seven (100%) patients in the Vancouver group felt satisfied. No patients were disappointed with the RTHA.

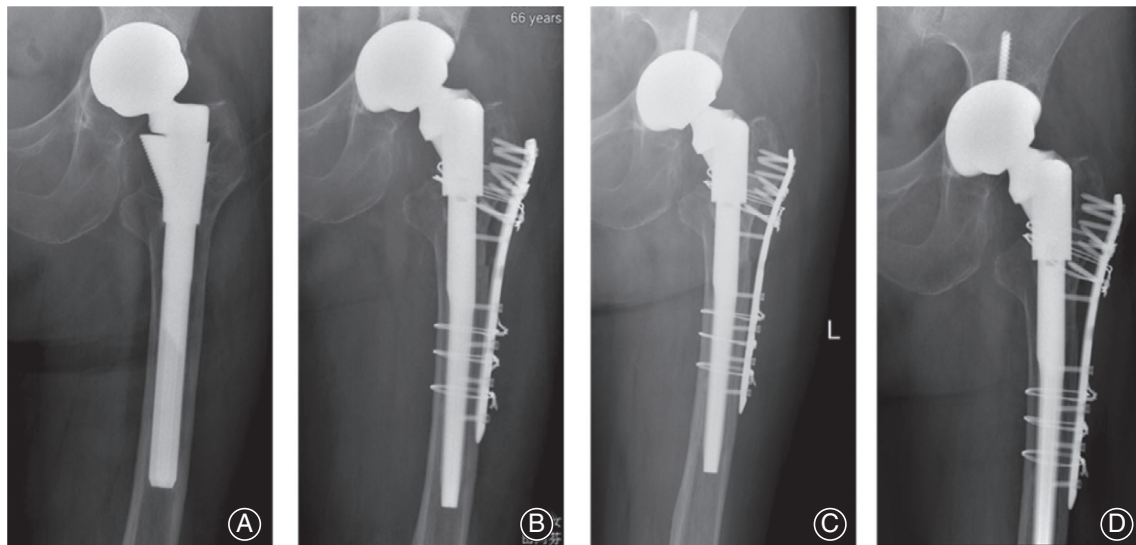
### Complications

Overall, we observed that three (9%) intraoperative fractures happened when the LINK stem was inserted, and four (12%) fractures occurred during the removal of the initial stem (Table 4). All fractures were treated with plates, single cortical

**TABLE 2** Operative data

Parameters	Paprosky II/III/IV	Vancouver B2/B3	Total
Operative Duration* (min)	192.9 ± 70.1 (range, 115 to 335)	165.3 ± 21.8 (range, 132 to 189)	187.2 ± 63.9 (range, 113 to 335)
Length of Incision* (cm)	19.5 ± 5.2 (range, 10 to 28)	18.9 ± 5.2 (range, 14 to 30)	19.4 ± 5.2 (range, 10 to 30)
Drainage Volume* (mL)	164.5 ± 134 (range, 11 to 580)	166.4 ± 63.9 (range, 90 to 260)	164.9 ± 122 (range, 11 to 580)
Drainage Duration*(h)	53.3 ± 12.2 (range, 24 to 72)	51.4 ± 9.1 (range, 48 to 72)	52.9 ± 11.4 (range, 24 to 72)
Blood loss (mL)	1129 ± 734 (range, 200 to 3000)	842.9 ± 287 (range, 400 to 1200)	1070 ± 673 (range, 200 to 3000)
Blood transfusion (mL)	948.1 ± 735 (range, 0 to 2900)	521.4 ± 376 (range, 0 to 950)	860.3 ± 694 (range, 0 to 2900)
Bone graft†	20 (74%)	7 (100%)	27 (79%)
ETO†	10 (37%)	0 (0%)	10 (29%)
Auxiliary fixation†,‡	10 (37%)	6 (86%)	16 (47%)
Hospital Stay* (days)	15.6 ± 6.3 (range, 7 to 37)	15.0 ± 6.2 (range, 9 to 28)	15.4 ± 6.2 (range, 7 to 37)

\* The value is given as the mean and the standard deviation, with the range in parentheses.; † The value is given as the number of hips, with the percentage in parentheses.; ‡ Auxiliary fixation: plates, single cortical screws or cerclage wires.



**Fig. 5** Radiographs of a 66-year-old female who underwent hip revision 10 years after THA. (A) Radiograph before revision, showing a loosened cementless stem. (B) Postoperative radiograph with the use of ETO. (C) Radiograph at 5 years postoperative. (D) Radiograph at 10 years postoperative.

screws, or cerclage wires for stable fixation. Three (9%) cases with infection were observed after revision, of which one case was treated by intravenous antibiotics and debridement, one case was treated by the vacuum sealing drainage (VSD) method, and one case needed re-revision. Three (9%) patients in the Paprosky group and three (9%) patients in the Vancouver group had lower limb vein thrombosis, which was successfully treated by routine anticoagulant therapy. One (3%) patient in the Vancouver group was observed with artery thrombosis, which was treated with a strainer. One (3%) dislocation case happened in the Paprosky group, and re-revision was needed for reduction. No non-union ETO occurred in either group. One (3%) case of aseptic loosening took place 5 years after revision.

#### **Fixation of Femoral Stem**

Radiographic evaluation demonstrated that 30 (88%) femoral stems remained stable, while three (9%) stems attained stable fibrous fixation. Moreover, one (3%) stem displayed unstable fixation (Table 5). The integrin of allograft bone was satisfactory with enough osteointegrin in all cases.

#### **Subsidence of Femoral Stem**

For the range of femoral stem subsidence, the mean subsidence of all stems was  $3.9 \pm 2.2$  mm (range, 1 to 10 mm). Of these, five (19%) stems in the Paprosky group and one (14%) stem in the Vancouver group subsided over 5 mm, but all subsidence stabilized after 1 year without further progression.

**TABLE 3 Clinical data at preoperative and mean 9.1 years postoperative**

Parameters	Preop.*		Postop.*		P value	
	Paprosky II/III/IV	Vancouver B2/B3	Paprosky II/III/IV	Vancouver B2/B3	Preop.*	Postop.*
HHS score†(points)	43.6 (17 to 67)		86.5 (67 to 97)		<b>0.001</b>	
Overall	[39.6 to 47.6]		[84.2 to 88.8]			
Pain	17.4 (0 to 30)	18.6 (10 to 20)	41.4 (30 to 44)	41.1 (40 to 44)	0.66	0.89
	[14.8 to 20.0]	[15.1 to 22.1]	[39.6 to 43.2]	[39.3 to 43.0]		
Function	21.6 (10 to 35)	18.6 (10 to 25)	38.1 (30 to 45)	39.7 (38 to 40)	0.25	0.247
	[19.2 to 24.0]	[13.4 to 23.7]	[36.7 to 39.5]	[39.0 to 40.4]		
Deformity	2.5 (1 to 4)	2.7 (1 to 3)	3.4 (2 to 5)	3.6 (3 to 4)	0.42	0.54
	[2.2 to 2.7]	[2.0 to 3.4]	[3.2 to 3.7]	[3.1 to 4.1]		
Activity	2.6 (1 to 4)	2.0 (1 to 3)	3.2 (2 to 4)	3.1 (3 to 4)	0.046	0.53
	[2.3 to 2.9]	[1.5 to 2.5]	[3.1 to 3.5]	[2.8 to 3.5]		
Subtotal	44.1 (17 to 67)	41.9 (30 to 50)	86.2 (67 to 97)	87.6 (85 to 92)	0.66	0.64
	[39.2 to 48.9]	[34.3 to 49.4]	[83.4 to 89.1]	[85.0 to 90.1]		
VAS score†(points)	7.1 (6 to 10)		1.1 (0 to 3)		0.36	
Overall	[6.8 to 7.5]		[0.8 to 1.4]			
Subtotal	7.1 (6 to 9)	7.3(6 to 8)	1.1 (0 to 3)	1.0 (0 to 2)	0.66	0.18
	[6.7 to 7.5]	[6.6 to 8.0]	[0.8 to 1.5]	[0.5 to 1.5]		
Satisfaction (no. of hips)‡						
Satisfied	—	—	24 (89%)	7 (100%)	-	-
General	—	—	3 (11%)	0 (0%)	-	-
Dissatisfied	—	—	0 (0%)	0 (0%)	-	-

\*Preop., preoperative; Postop., postoperative; HHS, Harris Hip score; VAS, visual analogue scale.; † The value is given as the mean, with the range in parentheses and the 95% CI in brackets.; ‡ The values are given as the number of hips, with the percentage in parentheses.

**TABLE 4 Complications**

Parameters	Paprosky II/III/IV	Vancouver B2/B3	Total
Intraoperative fracture†			
Inserting stem	2 (7%)	1 (14%)	3 (9%)
Removing stem	3 (11%)	1 (14%)	4 (12%)
Infection†	2 (7%)	1 (14%)	3 (9%)
Thrombosis†			
Vein	3 (11%)	3 (43%)	6 (18%)
Artery	0 (0%)	1 (14%)	1 (3%)
Dislocation†	0 (0%)	1 (14%)	1 (3%)
ETO nonunion†	0 (0%)	0 (0%)	0 (0%)
Postop. Peri-prosthesis fracture†	0 (0%)	0 (0%)	0 (0%)
Aseptic loosening†	1 (4%)	0 (0%)	1 (3%)
Modular junction Fracture†	0 (0%)	0 (0%)	0 (0%)

ETO, extended trochanteric osteotomy; Postop., postoperative.; † The value is given as the number of hips, with the percentage in parentheses.

### Stress Shielding

In addition, one out of 34 stems (3%) developed severe stress shielding accompanied by thigh pain, which required nonsteroidal anti-inflammatory drugs (NSAIDs) for relief.

### Leg Length Discrepancy

The averaged leg length discrepancy in all patients was  $3.3 \pm 2.7$  mm (range, 0 to 10 mm). Three (11%) patients in

the Paprosky group and four (43%) patients in the Vancouver group experienced a discrepancy of leg length over 5 mm, and we attempted to correct all cases within 10 mm.

### Survivorship

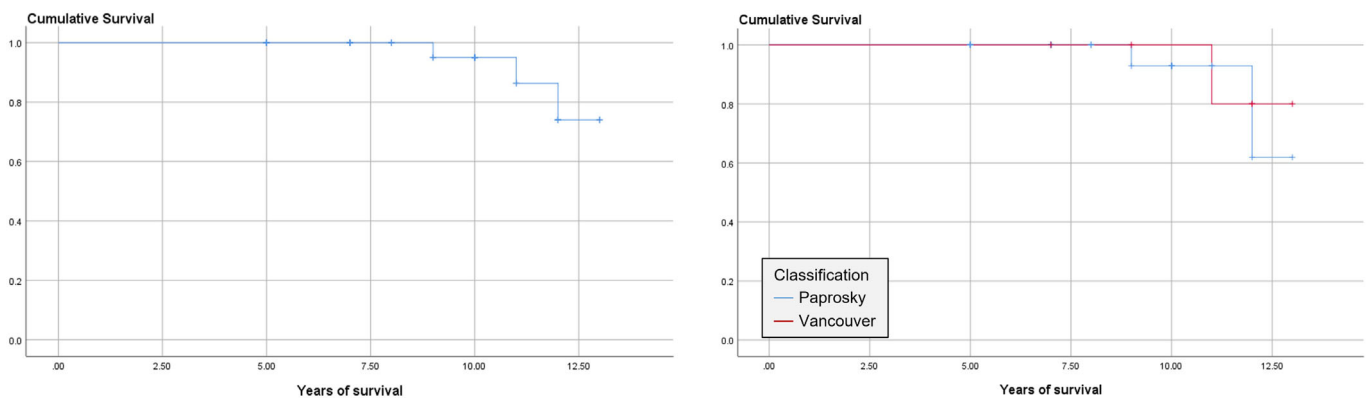
During the follow-up, three (9%) re-revisions were needed, including one for aseptic loosening, one for dislocation, and one for infection. There was no modular junction fracture in our study. As shown in Fig. 6, the overall cumulative



**TABLE 5 Radiographic data**

Parameters	Paprosky II/III/IV	Vancouver B2/B3	Total
Femoral stem fixation†			
Stable	25 (92%)	5 (71%)	30 (88%)
Fibrous fixation	1 (4%)	2 (29%)	3 (9%)
Unstable	1 (4%)	0 (0%)	1 (3%)
Subsidence*	3.8 ± 2.4 (range, 1 to 10)	4.1 ± 1.8 (range, 2 to 7)	3.9 ± 2.2 (range, 1 to 10)
≤5 mm	22 (81%)	6 (86%)	28 (82%)
>5 mm	5 (19%)	1 (14%)	6 (18%)
Integrin of allograft bone†	27 (100%)	7 (100%)	34 (100%)
Leg length discrepancy*(mm)	2.7 ± 2.4 (range, 0 to 10)	5.7 ± 2.7 (range, 1 to 9)	3.3 ± 2.7 (range, 0 to 10)
≤5 mm	24 (89%)	4 (57%)	28 (82%)
>5 mm	3 (11%)	3 (43%)	6 (18%)

\* The values are given as the mean and the standard deviation, with the range in parentheses.; † The value is given as the number of hips, with the percentage in parentheses.

**Fig. 6** (A) Kaplan–Meier overall survival rate. (B) Kaplan–Meier survival rate according to the classification (Paprosky & Vancouver).

Kaplan–Meier survivorship with re-revision for any reason as the end-point was 95% at 10 years after surgery and 74% (95% CI, 12.0 to 13.0) at 13 years follow-up. The subgroup analysis of Kaplan–Meier survivorship is shown in Fig. 6.

### Discussion

Revision THA with massive bone defects indicates a complex challenge to perform and reconstruct the bone stock. Numerous different designs of prostheses, including cemented stems<sup>9</sup>, uncemented long stems<sup>10</sup>, cylindrical stems<sup>11</sup>, and monoblock tapered stems<sup>12</sup>, have been applied to treat this problem during RTHA. For Paprosky types I and II bone defects, these strategies have been associated with acceptable long-term results; however, for severe bone loss, such as Paprosky type IIIA, IIIB, and IV, and Vancouver types B2 and B3, modular, fluted, tapered stems were considered to have the potential advantage of achieving long-term fixation<sup>17</sup>. In our study, we focused on the strategy

of the LINK MP stem, which has exhibited satisfactory short- to mid-term results in previous studies<sup>25, 39, 40</sup>, whereas the long-term results in functional restoration, pain relief, complications, and survivorship of stem have been less frequently reported.

### Clinical Evaluation

HHS is the major tool used to evaluate the clinical outcome of hip surgery and incorporates dimensions of pain, function, deformity, and activity<sup>30</sup>. The pain and function scores contribute to over 90% of the HHS, which required doctors not only to focus on the surgery but also to manage the patients during the whole perioperative period, from the pre-operative plan to rehabilitation. In our study, the average HHS after RTHA improved dramatically and reached 86.5 points at the last follow-up, which is higher than that in previous studies, with 77 and 78 points at the latest follow-up<sup>38, 39</sup>. We believe that the better functional

outcomes in our study were associated with adequate reconstruction of extensive bone defects, reduced intervention in muscular attachments of the hip, the use of ceramic-to-ceramic surfaces in all patients and emphasized rehabilitation to enhance patient recovery after surgery.

The leg length discrepancy is vital for patients during the process of functional recovery and is related to back pain<sup>41</sup> and gait correction<sup>42</sup>. Weiss *et al.* showed that 33 (52%) patients had leg length discrepancies greater than 5 mm, and even two (3%) of these patients had leg length diversity over 30 mm<sup>39</sup>. Restrepo *et al.* demonstrated that leg length was corrected within 5 mm in 95 (78%) of the patients<sup>38</sup>. The mean difference in leg length in our study was 3.3 mm (range, 0 to 10), and the leg length discrepancy in 28 (82%) patients was within 5 mm, which was better than previous results. The balance of both leg lengths intraoperatively could be adjusted by modular stem, which was an important advantage of the modular design.

### Intraoperative Results

Intraoperative femoral fracture was not uncommon during RTHA. Wang *et al.* observed that 10 out of 58 (17%) intraoperative femoral fractures happened during RTHA, which might be attributed to their lack of use of extended trochanteric osteotomy (ETO)<sup>25</sup>. ETO was reported to decrease the potential risk of intraoperative fracture during RTHA<sup>43</sup>. In addition, Ovesen *et al.* revealed that four (3%) fractures were detected intraoperatively<sup>24</sup>. Brown *et al.* showed that four out of 58 (7%) patients had intraoperative femoral fracture due to severe bone loss without adequate supportive bone<sup>18</sup>. The percentage of intraoperative femoral fracture in our research was 21%, which was higher than the proportion in previous studies. Consequently, more attention should be paid to prevent fracture during RTHA, for example, reaming by hand to centralize within the canal. Moreover, cerclage wire was considered a useful tool to protect the intact femur and avoid fracture. Furthermore, an appropriate stem size with routine fluoroscopy was helpful to reduce the risk of fracture intraoperatively.

Most patients in our study sustained bone grafting, which was beneficial for large metaphyseal bone loss to improve bone regeneration. In contrast, Wang *et al.* illustrated that none of their patients received bone grafts, and no patients had fatigue junction fractures during 3–7 years of follow-up<sup>25</sup>. However, we still suggest that bone grafts should be applied to patients with massive bone defects during RTHA to accelerate new bone formation and provide adequate support for implants.

### Complications

The subsidence of the femoral stem was considered one of the most common risks for re-revision<sup>44</sup>. Moreover, the design of modular stems is commonly accompanied by early subsidence<sup>45</sup>. Van Houwelingen *et al.* demonstrated that six out of 48 (12.5%) cases of substantial stem subsidence (>5 mm) happened with a mean subsidence of 12.3 mm and

achieved stability during the first year after RTHA<sup>45</sup>. Abdel *et al.* showed that 12 (2.4%) patients underwent stem subsidence >5 mm, and one of them exhibited progressive subsidence<sup>46</sup>. In our study, the average subsidence of the stem was 3.9 mm (range, 1 to 10), and six out of 34 (18%) cases subsided over 5 mm, which was higher than that in a previous study and met the features of the modular stem. Additionally, early weight-bearing and lower bone mass and quality might trigger stem subsidence in our study. However, no stem demonstrated progressive subsidence 1 year postoperatively. The risk of increased subsidence was affected by several factors. First, inappropriate and undersized stem diameter was found to be the key factor for progressive subsidence; therefore, the choice of a larger stem size and an increased 1–2 reamer size was suggested<sup>44</sup>. Second, the MP stem was designed with a 3° bow that accommodated the canal filling to provide better initial stability<sup>40</sup>. Moreover, the assistance of intraoperative fluoroscopy could help surgeons evaluate endosteal contact and implant position to avoid progressive subsidence.

Dislocation was another severe complication after RTHA. A high rate of dislocation was related to low femoral offset and deficient soft tissue. Weiss *et al.* showed that 17 (19%) dislocations occurred after RTHA within a minimum of 5 years of follow-up<sup>39</sup>. Wang *et al.* indicated that two of 58 (3.4%) hips dislocated after RTHA and that one patient needed further re-revision<sup>25</sup>. In our study, the number of dislocation cases was one (2.9%), which was lower than that in a previous study. The low rate of dislocation might be attributed to the modular design of the implant, which permitted adjustments of version and offset, good protection of the hip abductor mechanism during the surgical procedures, and use of the largest possible head size.

### Survivorship

Modular junction fracture has been regarded as a potential risk for the design of modular stems. Several studies have already reported such a situation. Lakstein *et al.* revealed that six out of 165 (3.6%) stems had a fracture at the junction of the modular implant<sup>47</sup>. The analysis of risk factors including excessive body weight, inadequate bone support, osteolysis, loosening, and undersized prostheses were reported to lead to junction fracture. Van Houwelingen *et al.* demonstrated that five out of 48 (10.4%) patients experienced stem fracture of the modular junction with the standard ZMR® design<sup>45</sup>. The poor proximal femoral bone stock was identified as the vital factor for junction fracture in this study. Notably, Rodriguez *et al.* recorded one fractured stem in a Paprosky type IIIB patient<sup>40</sup>. The heavy weight and inappropriate size of the stem contributed to stem fracture. In our study, no case of junction fracture was observed, which might be due to the good bone reconstruction around the femoral proximal canal at the modular junction followed by adequate diaphyseal fit and no excessive BMI of patients, therefore indicating the long-term survivorship of the modular stem under adequate bone reconstruction.

### Limitations of the Study

There were some limitations of our study. First, our study was a retrospective study, which means that bias related to review and data was unavoidable, although we attempted to review each record precisely and objectively. Further prospective randomized controlled trials are essential. Second, the number of cohorts for RTHA with extensive bone loss was still not large enough, which might decrease the incidence of complications. Moreover, this study focused on only one type of stem without comparison to other alternative prostheses for massive

femoral bone loss RTHA, which might be accompanied by selection bias. Finally, this was a single-centre study, and all operations were performed by a single surgeon. Future multicentre design with a large cohort is needed for further investigation.

### Conclusions

The mid- to long-term outcomes of revision total hip arthroplasty with the cementless modular, fluted, tapered stem are inspiring for massive proximal femoral bone defects.

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