Comparison of Clinical Outcomes, Radiological Outcomes and Bone Remodeling Outcomes Between Proximal Coated Single-Wedge New Stem and Full Coated Dual-Wedge Classic Stem in 1-Stage Bilateral Total Hip Arthroplasty

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Data Collection **B**
Statistical Analysis **C**
Data Interpretation **D**
Manuscript Preparation **E**
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Source of support: Departmental sources

Background: This retrospective study investigated the clinical outcomes, radiological outcomes, and bone remodeling patterns associated with a Medial/Lateral Taper (M/L Taper) stem and Link Classic Uncemented (LCU) stem in 1-stage bilateral total hip arthroplasty (THA).

Material/Methods: The results of 52 patients who underwent 1-stage bilateral THA with a M/L Taper stem on one side and an LCU stem on the other between January 2012 and February 2015 were retrospectively compared. Patients were clinically assessed by the Harris hip score (HHS), visual analogue score (VAS) and incidence of complications. Radiological indicators were measured. Periprosthetic bone remodeling was assessed via bone mineral density (BMD) measurements.

Results: The mean follow-up time was 5.2 years. At each follow-up, there was no difference in the HHS and VAS between the 2 groups. The neck-shaft angle, offset, vertical height of the rotational center and limb lengthening were lower in the M/L Taper group than in the LCU group (*P*<0.001). The Engh total score was lower in the LCU group (*P*=0.039). Significantly higher (*P*<0.001) BMDs were observed in the M/L Taper group in Gruen zones 1, 2, and 6. significantly lower (*P*<0.001) BMDs were observed in the M/L Taper group in Gruen zones 3 and 5.

Conclusions: Due to the increased postoperative neck-shaft angle, the full coated dual-wedge classic stem was prone to cause lower limb lengthening. The proximal coated single-wedge new stem patients were more likely to have an insufficient postoperative neck length. The new stem achieved load transfer and proximal fixation, leading to better proximal femoral bone preservation is more in line with human biomechanical characteristics.

MeSH Keywords: Arthroplasty, Replacement, Hip • Bone Density • Femur Head Necrosis • Hip Prosthesis

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/921847

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CLINICAL RESEARCH

Background

In the last few decades, strong evidence has supported the use of cementless prostheses, with many studies describing excellent results, including good functional outcomes and high long-term survival rates [1–4]. Along with the trends in population ageing and increased life expectancy, a surging number of total hip arthroplasties (THAs) are being performed in active and young patients; Therefore, expectations for THA are increasing, particularly regarding long-term survival and comfort [5–7]. Anatomical reconstructions and biomechanical reconstructions are effective guarantees for good joint arthroplasty prognoses [8,9]. Anatomical reconstruction includes femoral offset reconstruction and limb length reconstruction, which are determined by the prosthesis design, surgeon's skills, existing diseases and so on [10,11]. Altered load transfer after THA results in femoral bone remodeling [12,13]. A retrospective study of the changes in bone mineral density (BMD) around the prosthesis can be used to evaluate the stress shielding and bone reconstruction around the prosthesis, which is of great significance for improving the prosthesis design, predicting the fracture or loosening around the prosthesis, and assisting clinical decision-making [14].

At present, various types of cementless femoral prosthesis have been widely used by surgeons [15–17]. It has been demonstrated that proximal coated single-wedge new stems (for example, the M/L Taper stem, Tri-Lock stem) optimize the tapered wedge fixation while providing secure mediolateral stability. The proximal circumferential coating of the stem facilitates mechanical fixation for a secure bone-implant interface [15]. The fully coated dual-wedge classic stems (for example, the LCU stem and Corail stem) are characterized by a dual-wedge design with a rectangular cross-section to ensure the femoral prosthesis proximal stability. Its full coating ensures rapid bone integration [16,17]. Each type of femoral component design has a different geometry and coating, accompanied by unique models of load transfer and stress shielding that induce specific bone remodeling around the prosthesis [18]. To assess the effects of stem differences on clinical outcomes, radiological outcomes and periprosthetic bone remodeling outcomes, previous studies had compared different femoral stems [19]. However, these studies had some limitations because they could not eliminate the effects of individual differences and age. The comparison of 1-stage bilateral THA provides a way to minimize the impact of these confounding factors [20–22]. In our retrospective study, we investigated the clinical outcomes, radiological outcomes and periprosthetic bone remodeling outcomes of patients who underwent 1-stage bilateral THA with a M/L Taper stem on one side and an LCU stem on the other side.

Material and Methods

Study population

Between January 2012 and February 2015, 56 patients who underwent 1-stage bilateral THA with a M/L Taper stem on one side and an LCU stem on the other side were retrospectively analyzed. Four patients were lost to follow-up and 52 patients were finally enrolled in the study. The criteria for inclusion were as follows: patients with stage III or IV osteonecrosis of the femoral head (ONFH) or osteoarthritis grades III or IV who underwent bilateral THA at one time or unilateral THA, with both procedures performed within one month [23,24]. However, the following patients were excluded from this study: abnormal anatomical deviations of the proximal femur (neck-shaft angle <115°, or >150°), an inconsistent the bilateral femoral medullary cavity according to the Dorr classification, other femoral deformities, osteoporosis, or hyperparathyroidism. There are various surgical methods for developmental dysplasia hip (DDH), and there are some special prostheses for DDH patients, so we excluded DDH patients from the study. Our hospital's Institutional Review Board approved this study. And this study was conducted in accordance with the Helsinki declaration. We recorded demographic characteristics such as sex, age, body mass index (BMI), preoperative diagnosis, smoking status, alcohol consumption status, and postoperative complications.

Prosthetic design

Both the M/L Taper stem (Zimmer-Biomet, Warsaw, USA) and the LCU stem (Waldemar Link GmbH, Hamburg, Germany) are cementless femoral stems made of titanium alloy (Ti6Al4V) that provide excellent biocompatibility and strength without excessive stiffness. LCU stem is the representative of the classic stem. The whole length of the LCU stem is coated with a hydroxyapatite layer. Its design features include a dual-wedge component, a straight profile with a rectangular cross-section and a tapered distal end to prevent bone contact [16,17]. The proximal end of the M/L Taper stem is coated with titanium plasma. The M/L Taper stem, which is a common type of new stem, has a single-wedge design, is tapered in the medial-lateral plane and is flatted in the anteroposterior plane. Its design features include a highly polished surface design at the distal end of the stem, distal flutes and a minimal lateral shoulder [15]. In this study, we routinely used the LCU stem and M/L Taper stem with standard offsets, with neck-shaft angles of 130° and 131°, respectively (Figure 1).

Surgical procedure and postoperative rehabilitation

In this study, all surgeries were performed by a senior surgeon (HY) using a minimally invasive posterolateral approach. The brief surgical procedures are described as follows: after
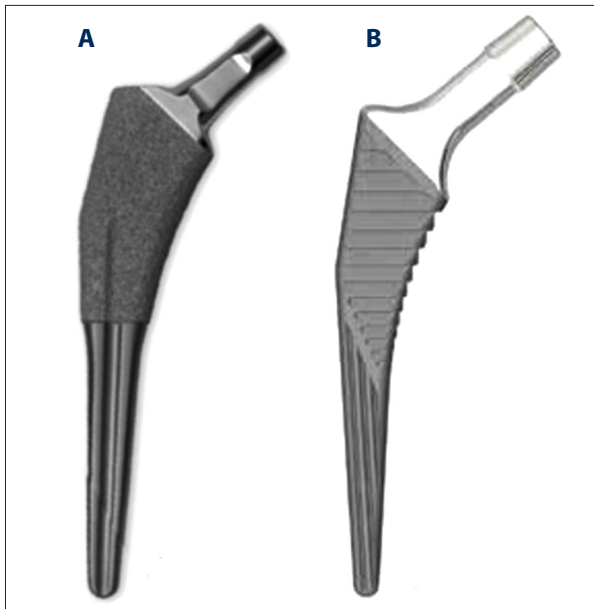
Figure 1. Anteroposterior view of 2 types of cementless femoral stems, which are made of titanium alloy (Ti6Al4V). (**A**) An M/L Taper stem with a proximal plasma coating. (**B**) An LCU stem with a full hydroxyapatite coating. M/L Taper – medial/lateral Taper stem; LCU – link classic uncemented stem.
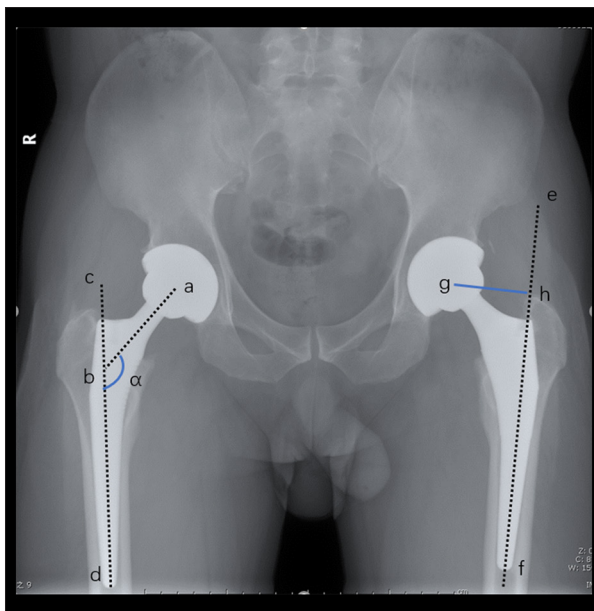

Figure 2. Radiological measurements of a patient on a bilateral proximal femur anteroposterior view x-ray examination. The neck-shaft angle (angle α) referred to the angle of intersection between the femoral shaft axis and femoral neck axis. The offset (solid blue lines [g-h]) referred to the vertical distance between the rotational center of the femoral head and the axis of the femoral shaft.

Figure 3. Radiological measurements of a patient on lower limb full-length view x-ray examination. The vertical height of the rotational center (solid black lines [a-b]) referred to the length between the rotational center and the tip of the lesser trochanter. The length of the lower limbs (solid black lines [c-d]) referred to the distance between the rotational center of the femoral head and the middle point of the ankle mortise.
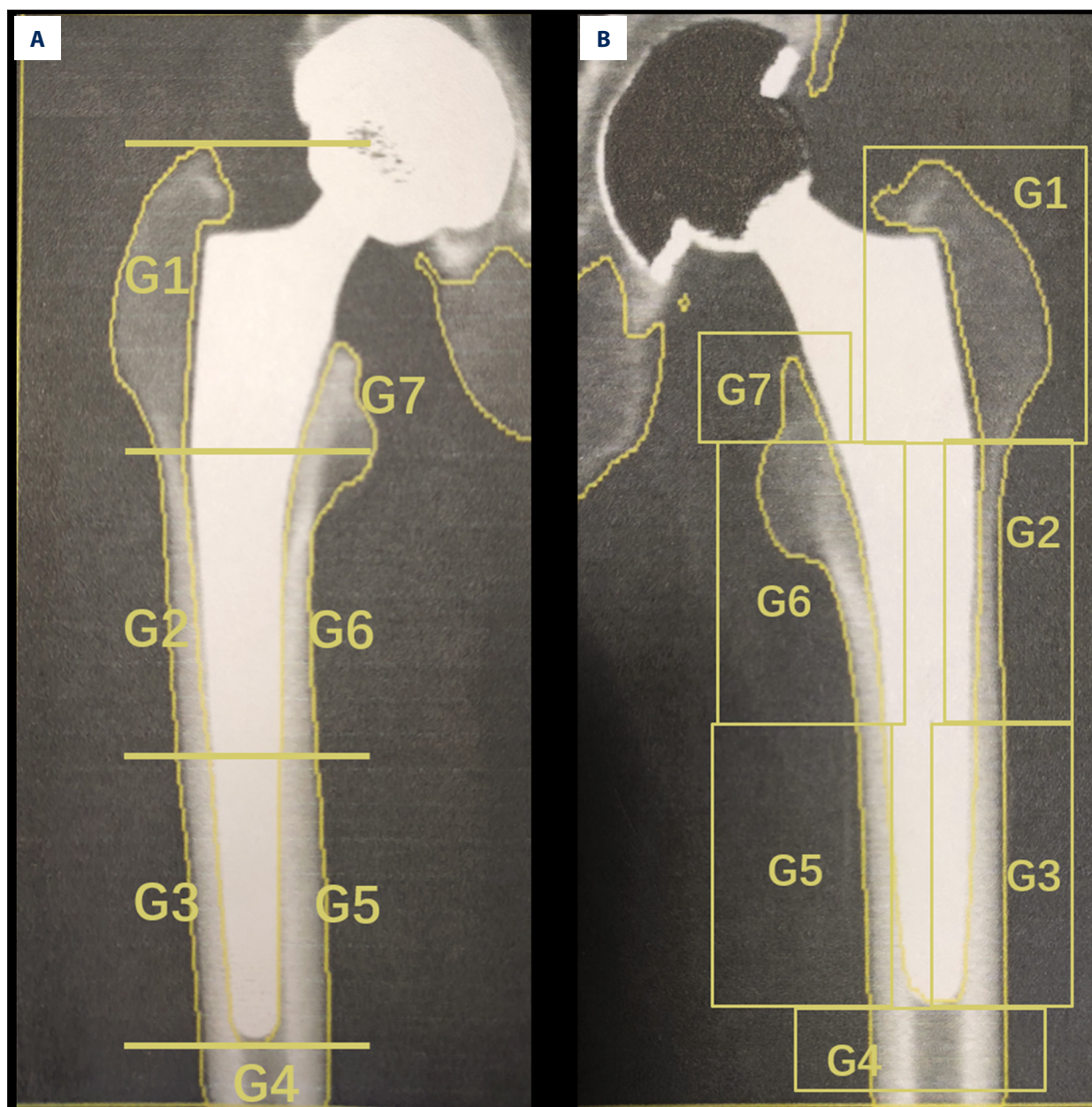
Figure 4. Dual-energy x-ray absorptiometry images with Gruen zone schemes (solid yellow lines). (**A**) LCU stem. (**B**) M/L Taper stem. In both sides, the Gruen zones are numbered G1 to G7. The Gruen zone width is proportional to stem length. M/L Taper – medial/lateral Taper stem; LCU – link classic uncemented stem.

exposure of the hip joint, a neck osteotomy was performed. Then, the acetabulum was treated, and the acetabular prosthesis was implanted. Next, the femoral stem was implanted after medullary preparation. Finally, a femoral head prosthesis was applied, and reduce the hip. For acetabular fixation, we did not routinely use screws. All patients were treated with intravenous antibiotics to prevent postoperative infection. Low-molecular-weight heparin was administered, and a lower-extremity venous pump was administered to prevent thromboembolic events. Both groups participated in a standard postoperative

rehabilitation program; they were prompted out of bed on the day of surgery and maintained limited weight bearing with a walker for 2 weeks after surgery. After 2 weeks, the patients were encouraged to progress to walking without an assistive device according to their comfort level (except 3 patients who experienced an intra-operative periprosthetic fracture).

Outcomes of interest

All patients were evaluated in terms of clinical outcomes, radiological outcomes and bone remodeling outcomes.

At each follow-up, patients were assessed by the Harris hip score (HHS) and visual analogue score (VAS) evaluations; the same experienced evaluator was blinded to the implant type. Complications were also reviewed.

In all patients, the bilateral proximal femur in the anteroposterior view and lower limbs in the full-length view were evaluated with x-ray examinations preoperatively, 1 month postoperatively, and at the last follow-up. The preoperative proximal femoral morphology was assessed using the canal flare index and the Dorr classification. The patient needed to tilt both tip-toe slightly inward (15°) when taken anteroposterior-view radiograph examination. The offset referred to the vertical distance between the rotational center of the femoral head and the axis of the femoral shaft on the anteroposterior-view radiograph examination. The neck-shaft angle referred to the angle of intersection between the femoral shaft axis and femoral neck axis. The length of the lower limbs referred to the distance between the rotational center of the femoral head and the middle point of the ankle mortise. The vertical height of the rotational center referred to the length between the rotational center and the tip of the lesser trochanter (Figures 2, 3). Limb lengthening was defined as the difference between postoperative lower limb length and the preoperative ipsilateral lower limb length. The fixation and stability of the femoral stem were radiologically assessed by Engh scores at the last follow-up. All radiological measurements and evaluations were performed independently by 2 experienced surgeons; all measurements were averaged.

The pattern of periprosthetic bone remodeling was assessed using BMD measurements by dual-energy x-ray absorptiometry (DXA). We routinely performed BMD tests on THA patients. As a technique for measuring BMD changes, DXA can detect small changes of BMD around prosthesis after THA, which is facilitates the study of periprosthetic bone remodeling. We measured the preoperative proximal femoral BMD and the periprosthetic BMD in 7 conventional areas of interest based on Gruen zones by using Hologic Discovery instrument (Hologic Inc., Waltham, MA, USA) (Figure 4). Scanning was performed in a slightly internally rotated position to obtain a frontal view of the femur. All the results were reviewed by 2 experienced radiologists and then averaged. To test the interobserver and interobserver reproducibility, each measurement was measured independently and again after 1 week. All intraclass correlation coefficients used to evaluate reproducibility, were >0.9 in this study.

Statistical analysis

SPSS version 19.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. For continuous variables, data are expressed as the mean±standard deviation. Shapiro-Wilk test was used for data normality testing, and Levene test was used for variance homogeneity test. The canal flare index, HHS, VAS, Engh score, neck-shaft angle, vertical height of the rotational center, lengthening of the limbs, offset and BMD were compared preoperatively and at each follow-up using paired t-tests if the data followed a normal distribution. If the data had a skewed distribution, a nonparametric test (Mann-Whitney U test) was used. The McNemar's test was used to compare the difference of complication rate between the 2 groups. A P-value <0.05 was considered significant.

Results

Demographic information

A total of 52 patients (28 male and 24 female) were included in the study. The average age at operation was 51.21±12.99 years (range from 39 to 76 years), and the average BMI was 24.75±3.00 kg/m^2 (range from 18.51 to 29.73 kg/m^2). Forty-three patients were diagnosed with primary bilateral ONFH, and 9 were diagnosed with bilateral osteoarthritis. Of the 52 patients, 11 patients had hypertension, 5 patients had diabetes, 7 patients smoked, 9 patients consumed alcohol, and 12 patients had osteopenia. All patients had the same bilateral Dorr classification; 11 cases were type A and 41 cases were type B. In terms of preoperative measurements, the average canal flare indices for the M/L Taper and LCU groups were 4.56±0.46 and 4.53±0.44, respectively (t=1.568, P=0.123). In addition, the average neck-shaft angle for the M/L Taper group was 133.10±3.24° and for the LCU group was 132.25±3.04° (t=1.492, P=0.142). The average offset for the M/L Taper group was 44.35 mm ± 5.51 mm and for the LCU group was 44.23 mm ± 5.65 mm (t=1.868, P=0.067). There was no difference (t=1.783, P=0.081) between the M/L Taper group and the LCU group (57.40±4.83 mm versus 57.23±4.70 mm) in the vertical height of the rotational center. There was no difference (t=1.791, P=0.079) between the M/L Taper group and the LCU group (84.00±5.73 cm versus 84.32±6.22 cm) in the lengthening of both lower limbs. The preoperative overall HHS for the M/L Taper and LCU groups were 40.77±8.00 and 39.81±7.76 (t=0.964, P=0.340), respectively. The preoperative VAS for the M/L Taper group was 6.81±1.62 and for the LCU group was 6.56±1.72 (t=0.842, P=0.404); no significant difference was observed.

Table 1. Clinical outcomes in patients who underwent 1-stage bilateral total hip arthroplasty by group.

	HHS				VAS			
	M/L Taper	LCU	t	P	M/L Taper	LCU	t	P
Preoperative	40.77±8.00	39.81±7.76	0.964	0.340	6.81±1.62	6.56±1.72	0.842	0.404
1-year post-operation	91.94±2.70	92.44±2.95	0.913	0.365	1.12±1.15	1.08±1.20	0.169	0.867
2 years postoperation	95.85±1.75	95.33±1.37	1.730	0.090	0.60±0.80	0.56±0.73	0.252	0.802
Last follow-up	96.29±1.29	96.19±1.30	0.373	0.711	0.52±0.70	0.46±0.64	0.387	0.700

N=52; paired *t*-test. Data are expressed as mean±standard deviation. HHS – Harris hip score; VAS – visual analogue score; M/L Taper – medial/lateral Taper stem; LCU – link classic uncemented stem.

Table 2. Incidence of complications in patients who underwent 1-stage bilateral total hip arthroplasty by group.

	M/L Taper		LCU		Statistic	P
Intra-operative periprosthetic fracture	2/52	(3.85%)	1/52	(1.92%)	0.000	1.000
Postoperative periprosthetic fracture	0/52	(0.00%)	1/52	(1.92%)	0.000	1.000
Dislocation	2/52	(3.85%)	0/52	(0.00%)	0.500	0.500
Heterotopic ossification	0/52	(0.00%)	1/52	(1.92%)	0.000	1.000
Thigh pain	2/52	(3.85%)	7/52	(13.46%)	1.778	0.180
Surgical site Infection	0/52	(0.00%)	0/52	(0.00%)	N/A	N/A
Total	6/52	(11.54%)	10/52	(19.23%)	0.643	0.424

N=52; McNemar's test. N/A – not applicable; M/L Taper – medial/lateral Taper stem; LCU – link classic uncemented stem.

Clinical outcomes

The average follow-up time of patients was 5.2 years (range from 4.1 years to 6.3 years). At 1-year and 2-year postoperatively and at the last follow-up, there were no difference in the HHS and VAS between the M/L Taper group and the LCU group. The HHS excellent-good rate was 100% in the M/L Taper group and 100% in the LCU group at the last follow-up (Table 1). At the last follow-up, all prosthetic stems survived.

In terms of complications, there were 2 patients (3.85%) with intra-operative periprosthetic femoral fractures in the M/L Taper group and one patient (1.92%) with intra-operative periprosthetic femoral fractures in the LCU group. All 3 fractures were classified as Vancouver B1. All patients were treated conservatively by limiting weight bearing for 6 weeks. All the fractures healed without other complications, such as infections or loosening. One patient (1.92%) in the LCU group presented a postoperative periprosthetic femoral fracture after an accident. The patient underwent reduction and internal fixation for fracture (Vancouver C), but the other limb with M/L Taper stem was not injured. There were 2 patients (3.85%) with dislocation in the M/L Taper group. These dislocations occurred 6 weeks and 8 weeks after surgery, and no further dislocation occurred after the closed reduction procedure. There was one patient (1.92%) in the LCU group with heterotopic ossification,

with no further treatment. The prevalence of thigh pain in the M/L Taper group was 3.85% (2 out of 52) and in the LCU group was 13.46% (7 out of 52). No surgical site infection occurred in this study. The overall complication incidence was 6 out of 52 (11.54%) in the M/L Taper group and 10 out of 52 (19.23%) in the LCU group, with no significant difference (McNemar's test; statistic=0.643, *P*=0.424) (Table 2).

Radiological outcomes

The postoperative neck-shaft angle was 130.79±3.42° in the M/L Taper group and 133.50±2.91° in the LCU group. The neck-shaft angle in the LCU group was higher than that in the M/L Taper group (*t*=5.344, *P*<0.001). The postoperative offset was 41.95±5.71 mm in the M/L Taper group and 46.40±4.75 mm in the LCU group. The offset in the LCU group was higher than in the M/L Taper group (*t*=4.293, *P*<0.001). The postoperative vertical height of the rotational center was 63.24±4.73 mm in the M/L Taper group and 67.54±5.76 mm in the LCU group, with a statistically significant difference (*t*=4.672, *P*<0.001). Postoperative limb lengthening was 2.97±7.23 mm in the M/L Taper group and 8.79±7.75 mm in the LCU group. Limb lengthening in the LCU group was significantly higher than in the M/L Taper group (*t*=4.359, *P*<0.001).

Table 3. Radiological outcomes in patients who underwent 1-stage bilateral total hip arthroplasty by group.

		M/L Taper	LCU	t	P
Neck-shaft angle		130.79±3.42	133.50±2.91	5.344	<0.001
Offset		41.95±5.71	46.40±4.75	4.293	<0.001
Vertical height of the rotational centre		63.24±4.73	67.54±5.76	4.672	<0.001
Limb lengthening		2.97±7.23	8.79±7.75	4.359	<0.001
Engh score (Last follow-up)	Fixation	9.51±1.50	9.22±1.84	0.903	0.371
	Stability	16.73±1.00	16.10±1.70	2.287	0.026
	Total	26.24±1.72	25.31±2.72	2.116	0.039

N=52; paired *t*-test. Data are expressed as mean±standard deviation. M/L Taper – medial/lateral Taper stem; LCU – link classic uncemented stem.

Table 4. Bone remodeling (g/cm^2) in patients who underwent 1-stage bilateral total hip arthroplasty by group.

	Preoperative				Last follow-up			
	M/L Taper	LCU	t	P	M/L Taper	LCU	t	P
Gruen 1	0.81±0.22	0.80±0.22	0.578	0.566	0.72±0.24	0.65±0.25	5.129	<0.001
Gruen 2	1.37±0.15	1.38±0.17	1.204	0.234	1.31±0.13	1.20±0.20	6.080	<0.001
Gruen 3	1.63±0.14	1.62±0.13	1.044	0.301	1.79±0.15	1.90±0.10	11.090	<0.001
Gruen 4	1.67±0.13	1.66±0.13	1.187	0.241	1.73±0.12	1.87±0.50	1.980	0.053
Gruen 5	1.43±0.17	1.43±0.17	1.196	0.237	1.78±0.16	1.89±0.15	12.212	<0.001
Gruen 6	1.51±0.15	1.52±0.16	0.974	0.335	1.45±0.12	1.40±0.10	10.394	<0.001
Gruen 7	0.97±0.24	0.97±0.23	1.146	0.257	0.83±0.37	0.77±0.78	1.358	0.181

N=52; paired *t*-test. Data are expressed as mean±standard deviation. M/L Taper – medial/lateral Taper stem; LCU – link classic uncemented stem.

The fixation and stability of the femoral stem were radiologically assessed by Engh scores. The Engh fixation score showed no difference between the M/L Taper and LCU groups (9.51±1.50 versus 9.22±1.84; *t*=0.903, *P*=0.371). The Engh stability score indicated better stability with the M/L Taper stem than with the LCU stem (16.73±1.00 versus 16.10±1.70; *t*=2.287, *P*=0.026). The total score showed a significant advantage of the M/L Taper stem compared to the LCU stem (26.24±1.72 versus 25.31±2.72; *t*=2.116, *P*=0.039) (Table 3).

Bone remodeling

According to the results of the DXA examinations, the preoperative BMD in each Gruen zone in the 2 groups was comparable (*P*>0.05). In 2 groups, the preoperative BMDs in Gruen zones 1 and 7 were less than those in Gruen zones 2, 3, 4, 5, and 6.

At the last follow-up, The BMDs were different between the 2 groups. Significantly higher BMDs were measured in the M/L Taper group than in the LCU group in Gruen zone 1 (0.72±0.24 g/cm^2 versus 0.65±0.25 g/cm^2; *t*=5.129, *P*<0.001), Gruen zone 2 (1.31±0.13 g/cm^2 versus 1.20±0.20 g/cm^2; *t*=6.080, *P*<0.001), and Gruen zone 6 (1.45±0.12 g/cm^2 versus 1.40±0.10 g/cm^2; *t*=10.394, *P*<0.001). In contrast, the M/L Taper group had significantly lower BMDs than the LCU group in Gruen zone 3 (1.79±0.15 g/cm^2 versus 1.90±0.10 g/cm^2; *t*=11.090, *P*<0.001) and Gruen zone 5 (1.78±0.16 g/cm^2 versus 1.89±0.15 g/cm^2; *t*=12.212, *P*<0.001). There was no difference in the BMDs in Gruen zone 4 (1.73±0.12 g/cm^2 versus 1.87±0.50 g/cm^2; *t*=1.980, *P*=0.053) and Gruen zone 7 (0.83±0.37 g/cm^2 versus 0.77±0.78 g/cm^2; *t*=1.358, *P*=0.181) (Table 4).

Discussion

The LCU and M/L Taper stem are both straight stems [15–17]. The major difference between the 2 kinds of stems is that the LCU stem, whose design conforms to the traditional concept, is fully coated with hydroxyapatite, while the M/L Taper stem, that has been generally accepted by surgeons in the last

2 decades, is proximally coated with titanium plasma. In this study, we compared the clinical results of 52 patients who underwent 1-stage bilateral THA with the LCU stem on one side and the M/L Taper stem on the other. In Gaku K's study [25], 36 patients who underwent 1-stage bilateral THA with 2 types of prosthesis were included. And in Chandran P's study [8], 22 patients were included. We believe that the sample size in the current study (52 patients) is large enough to support the reliability of the conclusions. All patients were followed up for at least 4 years.

The clinical outcome showed that both the LCU and M/L Taper prostheses performed well. In terms of complications, we observed no statistically difference between the groups. However, we hypothesized that periprosthetic fractures, dislocations, and thigh pain might differ if the study sample was large enough. Christensen et al. [26] reported that M/L Taper stems had a statistically higher periprosthetic fracture rate (5 out of 361, 1.4%) than full hydroxyapatite implants (0 out 789, 0%). They considered that the M/L Taper stem is plasma coated on the top half of the femoral stem and uncoated on the bottom half to reduce stress shielding. The abrupt transition in the M/L Taper stem increases the shear force on the proximal bone. The reduced fracture rate associated with the LCU stem demonstrates that stress is distributed both proximally and distally since there is no transition. Furthermore, a second hypothesis could be that the complication rate is related to the combination of the surgical technique and implant design [27]. Some studies have shown that an offset that is too little may lead to prosthesis dislocation [28,29]. In our study, the postoperative offset was less than the preoperative offset (41.95±5.71 mm versus 44.35±5.51 mm) in the M/L Taper group. A small offset can result in soft tissue relaxation and reduced mobility, which may lead to prosthesis dislocation. Thigh pain is a nonnegligible complication after THA. In our study, the prevalence of thigh pain was lower in the M/L/Taper group than in the LCU group (3.85% versus 13.46%), but the difference was not significant (*P*=0.180). The patients who experienced thigh pain reported mild pain and were not given pain medications. Fernandez et al. [30] and Incavo et al. [31] reported a prevalence of thigh pain as high as 12%, but in most cases, thigh pain was mild and did not limit hip function [30,31]. We considered that excessive reaming is one of the causes of thigh pain because femoral preparation typically requires distal reaming when patients receive an LCU stem, while canal is prepared with no distal reaming when patients receive an M/L Taper stem. However, we noted that distal coating material on the LCU stem extended to the femoral cortex and the stem tip; distal stress transfer is also a cause of thigh pain [32,33].

According to Jiang et al. [34], the mean neck-shaft angle for Chinese Han was 133°. The postoperative neck-shaft angle in the LCU group was larger (133.50±2.91° versus 132.25±3.04°),

while that in the M/L Taper group was smaller than the preoperative angle (130.79±3.42° versus 133.10±3.24°). Because of the relative fixation of the neck-shaft angle of the femoral prosthesis, the change in the neck-shaft angle after the operation was mainly due to the difference between the implanted prosthesis and the natural anatomical morphology of the femur. This indicates that the M/L Taper implant design tends to promote a varus deformity when reaming in the area around the greater trochanter is inadequate or when there is a partial inward opening of the medullary cavity. Judd et al. [35] reported that patients adjusted to a soft tissue balance after the operation, and the difference in neck-shaft angle had no significant effect on the postoperative effect. An effective reconstruction offset is very important for the recovery of hip joint function [36]. The offset has been shown to relate with hip stability, range of motion, abduction strength, wear, and impingement [37]. Compared with that before operation in our study, the offset in the LCU group was increased (46.40±4.75 mm versus 44.23±5.65 mm), while that in the M/L Taper group was decreased (41.95±5.71 mm versus 44.35±5.51 mm). This may have something to do with the neck length of the new stems changing with the stem size, whereas the neck length of the classic stem is fixed. There is no systematic study on the appropriate critical value of the femoral offset. A few studies suggested that an increasing femoral offset may improve the stability and range of motion of the hip joint, but these conclusions need to be further verified [28]. Leg length difference is a recognized common complication after THA [38,39]. It is widely believed that difference of more than 15 mm can lead to gait disorders, lower back pain, and general dissatisfaction [40]. However, some studies reported that differences in leg length was not associated with the feelings of patients [41]. Compared with before the operation in the current study, the length of the lower limbs increased in both groups, due to the replacement of the collapsed femoral head by the prosthetic femoral head. The vertical height of the rotational center in the LCU group was larger than that in the M/L Taper group, which caused the leg fixated to the LCU stem to lengthen. We believe that this is mainly due to the fact that the neck-shaft angle was larger, and the neck length was longer in the LCU group than in the M/L Taper group. However, the leg-length discrepancies are also influenced by other factors [10]. It appears that the offset in hips with LCU stems is larger than that in hips with M/L Taper stems. Due to the decreasing neck-shaft angle, we believe that the offset could be better reconstructed in hips with M/L Taper stems. Because of the lengthened prosthetic neck, with the reconstruction of the offset in hips with LCU stems, obvious leg lengthening was identified. If the lengthening in both legs is equalized, the relatively large neck-shaft angle results in an insufficient offset in hips with LCU stems. A perfectly fixed stem with absolutely no long-term radiologic changes, described as "mute x-rays", may be a logical goal but will be difficult to systematically achieve in reality. At the last

postoperative follow-up, the Engh scores based on radiological assessments in both groups indicated positive results. Both the stems showed good adaptation to the recipient bone without the loss of primary stability. According to Abdel et al. [42], the M/L Taper stem generally receives has a high Engh score, conserves metaphyseal bone stock and reduces the risk of stress shielding in the calcar, similar to the results in this study.

Improved bone preservation around the stem would make revision surgery less complex and reduce the risk of fractures around the prosthesis [8]. Medium- and long-term studies on bone remodeling and BMD around prosthesis with 2 different stems can help us discover the preservation and behavior of bone stock around prosthesis. Koyano et al. [25] found that the BMD of bilateral proximal femurs of the same person was similar in the same Gruen zone. It is known that individual differences and age are potential factors which affects BMD. The effect of those confounding factors can be minimized by comparing 1-stage bilateral THA with 2 types of prostheses. DXA is considered the most practical tool to measure bone remodeling after THA with different prosthesis designs [43,44]. Analysis of the 7 Gruen zones around the prosthesis is the most commonly method to evaluate bone reconstruction after femoral stem implantation. Some studies have reported that bone remodeling in the area around the prosthesis changes over time and reaches internal stability within about 2 years [45,46]. In our study, Gruen zones 3, 4, and 5 showed a slight increase in BMD compared with the preoperative densities, while Gruen zones 1, 2, 6, and 7 showed a slight decrease. This result is congruent with the existing literature on cementless designs, which shows that Gruen zones 3, 4, and 5 BMD stays relatively neutral or mildly increases postoperatively [44,47]. Compared with the preoperative values, Rahmy et al. [16] showed that BMDs were reduced in Gruen zones 1 and 7 and concluded that prosthesis design influences affect bone loss around prosthesis. Some studies recorded BMD losses in zones 1 [48], 1–2 [49], and 6–7 [45] when patients received an uncemented prosthesis. BMD was better preserved in Gruen zones 1, 2, and 6 but less preserved Gruen zones 3 and 5 around the M/L Taper stem than around the LCU stem. There seems to be a consensus that design, and fixation of the prosthesis is a major factor in influencing bone remodeling around the prosthesis [50]. The M/L Taper stem, with a larger diameter in the proximal area at the lateral cortex and the distal portion uncoated, led to better physiological strain distribution. The LCU stem is fully coated with hydroxyapatite and is easy to contact with the cortical bone. The distal cortex of the LCU stem was associated with increased BMD compared with the M/L Taper stem, suggesting the lateral femoral cortex and the stem tip received stress transduction. On the other hand, the distal portion of the M/L Taper stem is shortened, and the M/L taper stem is tapered in design, which results in less contact with cortical bones and less distal hypertrophy. The fact that we observed less BMD changes around the distal prosthesis of the M/L Taper stem than around the LCU stem suggests optimal proximal fixation and load transfer. Thus, the mechanical properties and load transfer characteristics of the prosthesis may lead to difference in the periprosthetic BMD in our study [51]. It is important to note that midterm bone remodeling does not necessarily reflect long-term consequences. Capello et al. [52] reported that one-third of THA patients showed additional late remodeling at 10 years after surgery; however, the implants remained fixed well, and the patients were clinically asymptomatic 15 years after the operation. More long-term follow-up studies are needed to confirm these findings.

Our study has several limitations. First, this was a retrospective single-center study that may have overlooked some important information and potential risk factors. Second, DXA does not provide information about the cortical, cancellous, and minute structures of bone. In addition, the spraying technology of these 2 implants is different. There are some reporters believe that different femoral stem coating might lead to different load transfer and stress shielding [25,26,53]. Therefore, the bone growth might be affected as a consequence of different spraying coat between these 2 femoral components. Finally, this study had a follow-up period of only 5 years. The long-term potential effects of BMD changes are unknown.

Conclusions

We analyzed the clinical outcomes, radiological outcomes and bone remodeling patterns in the 2 groups in detail. No significant differences were identified in the clinical outcomes between the 2 groups at the last follow-up. Due to the increased postoperative neck-shaft angle, the results demonstrated that the full coated dual-wedge classic stem was more likely to cause lower limb lengthening than the proximal coated single-wedge new stem, so surgeons need to pay additional attention during surgery to avoid leg-length discrepancies. Our results demonstrated that patients with proximal coated single-wedge new stem were more likely to have an insufficient postoperative neck length. Therefore, stems with lengthened heads might be considered during surgery to avoid insufficient offset and limb lengthening. In terms of bone remodeling, we found that the proximal coated single-wedge new stem met the goals of achieving load transfer and proximal fixation, which led to better the proximal femoral bone preservation and is more in line with human biomechanical characteristics. Whether the radiological outcomes and bone remodeling patterns associated with the full coated dual-wedge classic stem compared with the proximal coated single-wedge new stem change over a relatively long period of time requires further study.

Acknowledgements

We are grateful for the help of Dr. Xiaobo Wu for analysis of the radiography outcomes and to Dr. Huijie Li for help with collecting clinical data.

Conflict of interest

None.

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