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Are short-stem prostheses superior to conventional stem prostheses in primary total hip arthroplasty? A systematic review and meta-analysis of randomised controlled trials

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ABSTRACT

Objective Cementless total hip arthroplasty (THA) is associated with reliable clinical results and high patient satisfaction. Short-stem prostheses (SS) were designed to achieve superior preservation of proximal bone stock and stability compared with those of conventional-stem prostheses (CS). This meta-analysis was conducted to determine the proximal bone remodelling, revision rate, Harris Hip Score, radiolucent line and maximum total point motion values of both SS and CS for primary THA.

Method Relevant randomised controlled trials (RCTs) involving SS and CS in primary THA were identified from electronic databases, such as EMBASE, PubMed and the Cochrane Library.

Result Ultimately, 12 RCTs involving 1130 patients (1387 hips) were included. The results showed that compared with CS, SS resulted in less bone mineral density (BMD) changes in Gruen zone 7 at 1 year and 2 years postoperatively (mean difference (MD)=5.11; 95% CI, 1.61, 8.61; P=0.30; and MD=4.90; 95% CI, 1.01, 8.79; P=0.17, respectively). No difference in BMD changes was found for Gruen zone 1 (MD=2.66; 95% CI, −3.31, 8.64; P<0.00001), and no differences were observed for the revision rate (relative risk (RR)=1.52; 95% CI, 0.71, 3.26; P=0.94), Harris Hip Score (MD=−0.38; 95% CI, −1.02, 0.26; P=0.89) or stem migration (MD=0.02; 95% CI, −0.07, 0.11; P=0.04).

Conclusion Our results suggest that compared with CS, SS may provide superior bone remodelling and similar survival rates and clinical outcomes. However, the short-term follow-up of the included studies was inadequate to determine the long-term performance of SS.

Strengths and limitations of this study

► The present results derived from all available comparative data are the first to document the differences in postoperative bone remodelling, implant survival, complications and radiological performance between SS and CS.
► Although the most recent evidence regarding the use of SS and CS in primary THA were provided in our study, the average follow-up of 3.9 years (range, 0.115–11.8 years) was relatively short for evaluating the outcomes of femoral prostheses.
► The effects of the lateral flare design and the extent and type of surface coating for bone conservation in primary THA have not been fully defined.

INTRODUCTION

Total hip arthroplasty (THA) is an effective treatment method for hip disorders. Along with improved techniques and prosthetic designs, the number of THAs performed has increased worldwide.[1] Moreover, the overall burden of revision has increased,[2] particularly in patients who are young and thus have the potential for revision. The THA revision rate has significantly increased in patients aged between 45 and 64 years in the United States.[3] Therefore, optimal implant survival with reliable clinical outcomes and bone stock preservation are essential for facilitating future revisions. Conventional cementless femoral stems may provide satisfactory clinical and radiographic outcomes at long-term follow-up.[4–6] However, despite excellent results, stress shielding and thigh pain may occur.[7 8]

Stress shielding is associated with periprosthetic bone loss, which may contribute to late-occurring periprosthetic fractures in uncemented femoral stems.[9 10] First introduced in 1989,[11] short-stem prostheses (SS) were developed to preserve proximal bone stock and allow more physiological proximal loading.[12 13] The design of SS requires less resection of the femoral neck and less reaming of the femoral shaft. Although no exact definition of SS exists, these prostheses are characterised by their fixation principles and the location of proximal loading, with

stem lengths ranging from 40 to 135 mm.[14] According to some research, short stems typically do not extend beyond 120 mm in a majority of cases and a trochanter-sparing design is employed, which is uncemented with a proximal metaphyseal and short diaphyseal anchorage.[15] Previous studies on SS have shown excellent clinical results and fixation at short-term to mid-term follow-up.[16–18]

Some clinical studies compared the effectiveness and radiographical outcomes between SS and conventional stem prostheses (CS) in primary THA, and several studies reported superior bone preservation for SS after evaluating bone mineral density (BMD) changes around the prostheses.[19–21] However, other studies have reported different results.[22–24] A meta-analysis conducted by Huo et al[25] showed that SS achieved the same clinical and radiological outcomes as CS and additionally reduced thigh pain. However, the meta-analysis included only six studies with a small number of subjects: 275 hips in the SS group and 297 in the CS group. Their analysis did not evaluate bone remodelling outcomes, such as periprosthetic bone density and radiolucent lines and migration. Jahnke et al[26] observed that BMD changes did not directly correlate with clinical outcomes despite significant improvements in the Harris Hip Score (HHS). Because additional clinical trials were recently published, such results warrant re-evaluation. To survey superior survival rates and clinical outcomes in primary THA, we conducted a systematic review and meta-analysis to evaluate the evidence from all available randomised controlled trials (RCTs) that compared SS and CS in patients undergoing primary THA.

METHODS
Search strategy
We conducted a meta-analysis to identify relevant RCTs involving SS and CS in primary THA in electronic databases. Two reviewers independently searched electronic databases, including the Web of Science, EMBASE, PubMed, the Cochrane Controlled Trials Register and the Cochrane Library, through July 2017 using the following keywords and their combinations: short stem, conventional stem, arthroplasty, hip and randomised controlled trial. The reviewers first screened the titles and abstracts to identify the relevant studies. Only RCTs performed with humans were included. The search strategy is presented in online supplementary table 1. The PRISMA guidelines[27] and Cochrane Handbook were applied to assess the quality of the results published in all the included studies to ensure that the results of our meta-analysis were reliable and verifiable. The reference lists of the selected articles were also reviewed manually to identify additional relevant studies.

Inclusion and exclusion criteria
The inclusion criteria were defined before searching the databases, and study inclusion eligibility was determined by the following population, intervention, comparator, outcome and study design criteria: (1) patients with hip disorders, such as osteoarthritis, osteonecrosis, traumatic arthritis or femoral neck fracture and scheduled for primary THA; (2) RCTs comparing SS and CS; and (3) the age of the patients and follow-up periods were not restricted. The publication language was also limited to English. The exclusion criteria were as follows: observational studies, noncontrolled clinical trials, animal studies or revision THA.

Data extraction and quality assessment
Two investigators independently extracted the relevant data from each study, which included the first author's name, year of publication, country, study design, company, details of the intervention and control, and the follow-up duration and outcome measurements for each study. Any uncertainty was discussed by the two reviewers and resolved by consensus through discussion with other reviewers. We contacted the corresponding authors of the included RCTs when necessary to obtain any missing data . Revision rates were recalculated based on the number of revisions due to all causes provided in the article. The Cochrane Collaboration tool[28] was used to assess the methodological quality and risk of bias of the included studies, including randomisation, allocation concealment, blinding method, selective reporting, group similarity at baseline, incomplete outcome data, compliance, timing of outcome assessments and intention-to-treat analysis.

Outcome measurements
The primary outcome measurements evaluated in our meta-analysis included BMD changes in different femoral zones to assess the efficacy of short stems by evaluating whether they can achieve better bone remodelling, postoperatively measured by dual-energy X-ray absorptiometry (DEXA), and the revision rate to evaluate the safety of short-stem prostheses. The secondary outcomes were as follows: the Harris Hip Score to evaluate the functional outcome; the presence of radiolucent lines, which suggests loosening of the prosthesis; and the maximum total point motion to evaluate stem migration in three axial directions.

Statistical analysis and data synthesis
The meta-analyses were performed using Review Manager (Revman Version 5.3., the Cochrane Collaboration, Oxford, UK). Given the characteristics of the data extracted for the review, continuous outcomes were expressed as the mean difference with 95% CIs. An assumption that the standard deviations (SDs) of the outcome measurements were the same in both groups was required in all cases, and the SD would then be used for both intervention groups. Where actual P values obtained from t-tests are quoted, the corresponding t value may be obtained from a table of the t distributions. The df are given by $NE + NC - 2$, where NE and NC are the sample sizes in the experimental and control groups, respectively.

The t value is the ratio of the difference in means to the SE of the difference in means. The SE of the difference in means can therefore be obtained by dividing the difference in means by the t value: SE=MD/t. The within-group SD can be obtained from the SE of the difference in means using the following formula: SD=SE/$\sqrt{((1/NE)+(1/NC))}$. If authors do not report exact P-values but a 95% CI is available for the difference in means, then the same SE can be calculated as SE=(upper limit − lower limit)/3.92, as long as the trial is large. For 90% CIs, 3.92 should be replaced by 3.29, and for 99% CIs, this value should be replaced by 5.15. If the sample size is small, then confidence intervals should have been calculated using a t distribution. The numbers 3.92, 3.29 and 5.15 need to be replaced with larger numbers specific to both the t distribution and the sample size and can be obtained from tables of the t distribution with df equal to NE +NC − 2, where NE and NC are the sample sizes in the two groups, respectively. Relevant details related to the t distribution are available as appendices in many statistical textbooks or in standard computer spreadsheet packages. Heterogeneity was assessed using the I^2 statistic. $I^2 \geq 50\%$ represented high heterogeneity. To detect the impact of each data set on the overall effects of the analyses, sensitivity analysis was performed by sequentially deleting a single study involved in the meta-analysis. Subgroup analysis was performed based on the different follow-up periods. Risk ratios with a 95% CI were used to assess dichotomous outcomes. The inverse variance and Mantel–Haenszel methods were used to combine separate statistics. We evaluated whether asymmetry was due to publication bias or to a relationship between the trial size and effect size using funnel plots. A P value <0.05 was considered statistically significant.

Patient and public involvement

No patients or public were involved in this study.

RESULTS

Description of the included studies

An initial literature search yielded a total of 2773 relevant studies, of which 1104 were excluded as duplicates. After screening the titles and abstracts of the remaining studies, we identified 44 potentially relevant studies. After excluding 32 publications by full-text screening, 12 RCTs published from 2006 to 2017 involving eight different SS types and 1130 participants were ultimately included in the study (figure 1). The characteristics of the included studies are presented in table 1. The total sample size was 680 for the SS group and 707 for the CS group. The populations of the included studies ranged from 21 to 200 participants. The follow-up durations ranged from 6 weeks to 11.8 years (mean 3.9 years). All the femoral components were uncemented designs except for one that was cemented.[29] Ceramic-on-ceramic bearing surfaces were reported in five studies,[22–24 29–31] while other studies did not report this information. A one-stage bilateral

THA was performed in two studies.[21 24] The mean patient age was 62.7 years (range, 51.7–76.0 years), and 42.2% (range, 11%–63%) of the patients were men.

Risk of bias of the included studies

All included studies were RCTs, and two were performed at multiple centres, one of which was a double-blind RCT. Eight trials reported random sequence generation clearly and were defined as having a low risk of bias, while the remaining trials did not report their sequence generation. Thus, the risk of selection bias was unclear in the latter trials.[19 21 32 33] The blinding methods of two studies were considered to have a high risk of bias; in one trial,[20] the clinical and radiographical outcomes were assessed by the researchers and surgeon, and in another trial,[19] the participants were not blinded. Selective reporting, incomplete outcome data and other obvious biases were not observed, and these factors were judged as having a low risk of bias. Details of the bias assessment are shown in figure 2. Based on the high quality of the methodology used in registered trials published in the English-language literature, we hypothesised that the possible source of such bias might be affect size differences among the variously sized samples in our study.

OUTCOMES OF THE META-ANALYSES

Primary outcomes

BMD

In total, seven studies reported on the BMD of different zones according to Gruen's description, representing a total of 322 hips. The BMD was determined using DEXA in all of these studies. Five studies had a DEXA scan within the first week after surgery.[19–22 31] Sluimer et al[20] reported that DEXA scans were conducted at 4 to 7 days, 7 weeks and 3, 6, 12 and 24 months postoperatively, and all femoral prosthetic zones were measured. The results showed that the BMD around both femoral components decreased immediately after surgery in all the Gruen zones. After 2 years, this decrease was followed by an increase to 94% to 100% of the original BMD, except in Gruen zones 1 (G1) and 7. Freitag et al[22] reported that the BMD data were collected at 1 week and 3 and 12 months after surgery for all the zones. The result showed that on evaluation at 1 year, the BMD was lower than at the 7-day postoperative assessment for both implants in all zones, aside from G3 in the short-stem group, which showed a small increase. In addition, there was a significant difference in BMD changes at 1 year between the groups in G1 and (G6. The periprosthetic decrease in the BMD was most pronounced in G7 for both implants. Salemyr et al reported that DEXA scans were performed at 1 and 2 days and 3, 6, 12 and 24 months postoperatively, with reported BMD values in G1 and G7. Additionally, they reported the BMD changes of Gruen zones 1–7 together as an entity and found 5% lower bone resorption in the ultra-short group relative to the conventional group. Kim et al[24] reported that DEXA scans were performed at 1 week, 1 year, 10 years and at the
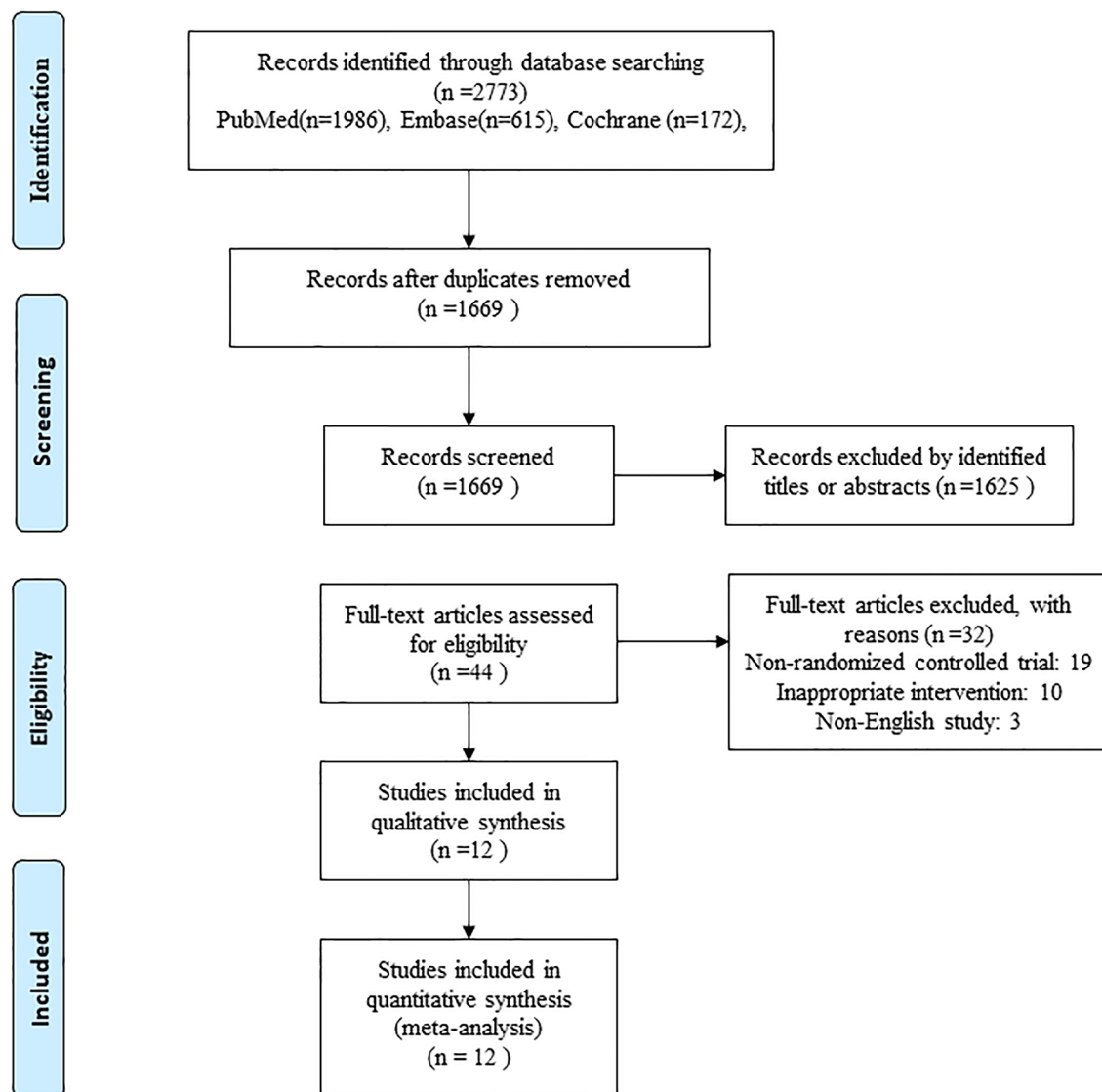
Figure 1 Flow diagram of the relevant study selection process.

final follow-up after surgery. BMD values were available in G1 and G7. Koyano et al[21] only measured BMD values at the final follow-up, and the result showed that BMD values in G2, G3 and G6 on the anatomic-stem side were significantly lower than those on the straight-stem side. DEXA scans were performed within 3 days after surgery and 1 and 2 years postoperatively. Schilcher et al[31] reported the BMD values of G1, G5 and G7, and their results showed no significant difference between the two groups at 1 year and 2 years after surgery. However, G5 was created by the authors within G1, which was different from the original description of the zones. Kim et al[23] reported the BMD values of G1 and G7, and the first DEXA scan was performed 1 week after surgery, with further scans obtained at the final follow-up (3 years postoperatively). The results indicated that in the short-stem group, the BMD at 3 years after surgery was significantly increased in G1 but slightly decreased in G7, and the BMD at 3 years after surgery was significantly decreased in G1 and G7. In the profile group, data recorded as BMD changes between

1 week postoperatively and 1–2 years postoperatively were available in five studies. Heterogeneity analysis demonstrated statistical evidence for variation within the study (I^2=82%). The BMD of both groups decreased in G1 and G7. Data pooled by random effects indicated no significant difference between SS and CS at both year 1 and year 2 postoperatively in zone 1 (MD=2.66; 95% CI, –3.31, 8.64; P<0.00001; figure 3). BMD changes in G7 differed significantly both at 1 year (MD=5.11; 95% CI, 1.61, 8.61; P=0.30) and at 2 years postoperatively (MD=4.90, 95% CI, 1.01, 8.79; P=0.17; figure 4) without any heterogeneity (I^2=0%), indicating more proximal bone loss in G7 in the CS group.

Revision rate

All included trials except one reported the revision rate as an outcome. Thus, 11 studies with 1307 hips involving 23 revisions were analysed (figure 5). The major reasons for revision were related to femoral stems with periprosthetic fractures, aseptic loosening and recurrent dislocations.

Table 1 Overview of the characteristics of the included studies

Study/year (country)	SS group/CS group				Follow-up (mean), years	Type of implant (company)	Dorr type			Outcome assessment
	Number of patients	Number of hips	Age (mean), years	Gender (% male)			Type A	Type B	Type C	
Sluimer et al[20]/2006(Netherlands)	80	40/40	53/56	37/43	2.0/2.0	Omnifit-HA1090 (Osteonics)/Omnifit-HA1017 (Osteonics)	NA			HHS, BMD, Engh score
Calsson et al[29]/2006 (Sweden)	52	24/29	59	NA	3.0/3.0	GOT (Astra Tech AB)/Spectrum (Smith & Nephew)	NA			HHS, VAS, radiograph (RSA)
Kim[23]/2011 (Korea)	100	60/60	54.3/51.8	44/48	3.3/3.4	Proxima (DePuy)/Profile (DePuy)	58/55	2/5	0	HHS, BMD, radiograph, activity score
Kim[24]/2012 (Korea)	140	70/70	74.9/76	27/24	4.1/4.8	Proxima (DePuy)/AML (DePuy)	6/8	21/18	43/44	HHS, WOMAC, UCLA activity score
Roth et al[33]/2014 (Germany)	80	40/40	60.1/64.8	58/48	0.115/0.115	Fitmore (Zimmer)/CLS (Zimmer)	NA			HHS, WOMAC, SF-36, radiograph
Salemyr et al[19]/2015 (Sweden)	51	26/25	62/62	59/43	2	Proxima (DePuy)/Bimetric (Biomet)	26	25	0	HHS, BMD, WOMAC, radiograph (RSA), EQ-5D, thigh pain
McCalden et al[32]/2015 (Canada)	43	22/21	62.8/66.6	37/38	2	SMF (Smith & Nephew)/Synergy (Smith & Nephew)	NA		0	HHS, WOMAC, SF-12, radiograph
Freitag et al[22]/2016 (Germany)	138	57/81	56.8/59.1	63/63	1.0/1.0	Fitmore (Zimmer)/CLS (Zimmer)	NA		0	HHS, BMD, WOMAC
Kim[30]/2016 (Korea)	200	200/200	52.5/52.5	69/69	11.8	Proxima (DePuy)/Profile (DePuy)	102/100	62/64	36/36	HHS, BMD, WOMAC, UCLA activity score, radiograph
Koyano et al[21]/2017 (Japan)	36	36/36	51.7	11/11	9.2	Super Secur-Fit (Stryker)/CentPillar GBHA (Stryker)	10/8	26/28	0	JOA hip score, BMD
Schilcher et al[31]/2017 (Sweden)	60	30/30	59.4/60.6	43/37	2.0/2.0	Taperloc Microplasty (Biomet)/Taperloc (Biomet)	21	39	0	HHS, BMD, WOMAC, radiograph (RSA)
Oldenrijk et al[36]/2017 (Netherlands)	150	75/75	60.3/60.5	28/29	2.0/2.0	CFP (Link)/Alloclassic Zweymuller (Zimmer-Biomet)	NA			HOOS, HHS, PCS-12, Pain-NRS Score, TUG, Trendelenburg test, EQ5D

AML, anatomical medullary locking fully porous coated cementless femoral component; BMD, bone mineral density; CFP, collum femoris preserving stem; CLS, cementless straight stem; CS, conventional stem prostheses; GOT, Gothenburg osseointegrated titanium hip; HA, hydroxyapatite; HHS, Harris Hip Score; HOOS, hip disability and osteoarthritis outcome score; JOA, Japanese Orthopaedic Association; MTPM, maximum total point motion; NA, not available; PCS-12: physical component scale of the SF12; RSA, radiostereometric analysis; SF-36: short form 36-item health survey; SMF, short metaphyseal fixation stem; SS, short-stem prostheses; TUG, timed up-and-go test; VAS, visual analogue scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Figure 2 Risk of bias summary for each included study.

We divided the revision rate in these studies into three groups (2 years, 2–8 years and 8 years) according to the timepoint at which the revision occurred. Heterogeneity analysis demonstrated no statistical evidence for variation within the study ($I^2=0\%$). No significant differences were observed regarding the revision rate results in any subgroup (2 years: RR=1.56; 95% CI, 0.46, 5.35; P=0.58, 2–8 years: RR=1.21; 95% CI, 0.40, 3.67; P=0.95) or in total (RR=1.52; 95% CI, 0.71, 3.26; P=0.94), indicating that, at an average follow-up of 3.9 years, revision for all causes was comparable between the two groups.

Secondary outcomes

HHS

A total of nine studies reported the HHS, encompassing 1150 hips, although HHS reporting for patients in the SS groups was more common (mean difference=−0.38). The combined data demonstrated no significant differences between the two groups (95% CI, −1.02, 0.26; P=0.89), with low heterogeneity ($I^2=0\%$)) at the latest follow-up (figure 6).

Maximum Total Point Motion

Three studies included 151 hips at the 1-year follow-up and 148 hips at the 2-year follow-up, and they reported the MTPM to evaluate femoral stem migration (figure 7). Pooled analyses were conducted using a random-effects model because of significant heterogeneity ($I^2=57\%$). No significant difference was found between the two groups at the different follow-up times (MD=0.09; 95% CI, −0.31, 0.49; P=0.11; and MD=0.21; 95% CI, −0.24, 0.56; P=0.56, respectively).

Radiolucent lines

A total of six studies[21–23 29 30 32] indicated that radiolucent lines existed around the femoral prostheses. Sufficient data were not available to conduct a meta-analysis for this variable. Radiolucent lines were observed in only two trials involving 15 subjects in the SS group and none in the CS group without clinical symptoms. Calsson et al[29] reported radiolucent lines in a thin zone adjacent to the proximal cranial fixation region of the femoral component in 14 patients. McCalden et al[32] reported aseptic loosening in one patient 3 years postoperatively who underwent revision because of pain and radiographical features with complete radiolucent lines around the proximal porous coating.

Sensitivity analysis

Sensitivity analysis was performed by individually removing each study to identify whether the pooled results changed. All results were stable except the BMD change in G7. At 2 years postoperatively, the difference between groups lost significance after one study was removed[20]; additionally, although the removal of the data from another study[31] at 1 year and 2 years postoperatively reduced the I^2 to 0%, it also resulted in a significant difference between the groups. Thus, based on the results of our analysis, SS is equally effective for preserving proximal bone stock.

DISCUSSION

This meta-analysis of 12 RCTs including 1130 patients and comparing the efficacy and safety of SS and CS showed more proximal bone loss in G7 in the CS group but no significant difference in G1 within 2 years postsurgery. We found no significant differences in the revision rate, HHS, maximum total point motion and radiolucent line.

Recently, the performance of SS in primary THA has been investigated, and the results have been
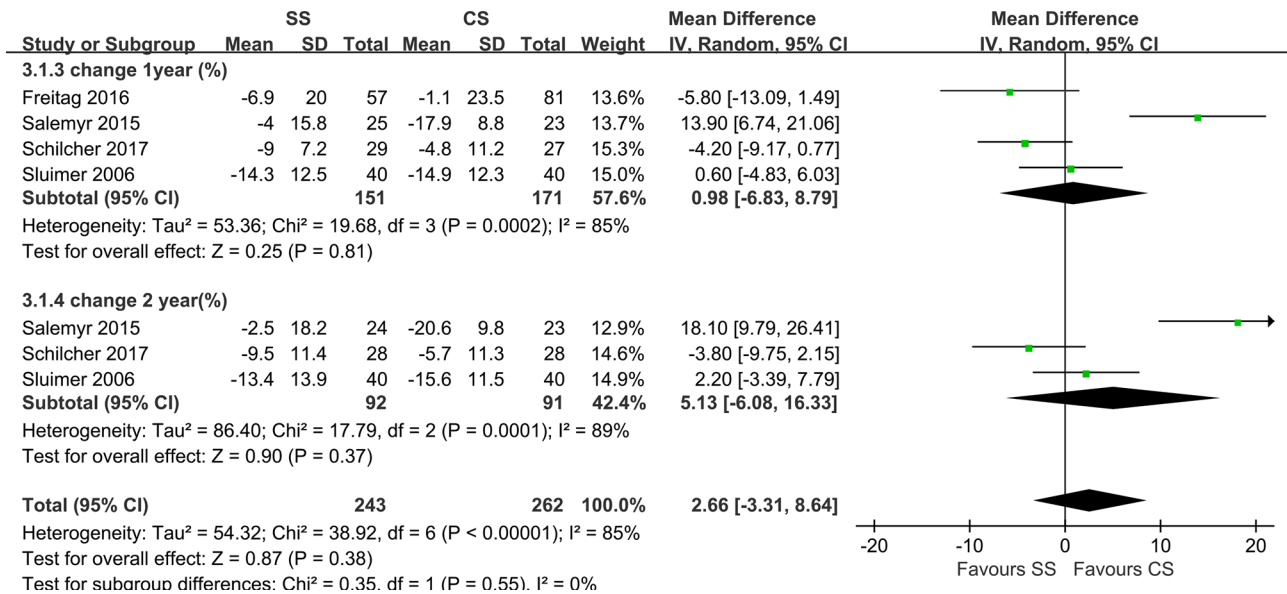
Study or Subgroup	SS Mean	SD	Total	CS Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
3.1.3 change 1year (%)								
Freitag 2016	-6.9	20	57	-1.1	23.5	81	13.6%	-5.80 [-13.09, 1.49]
Salemyr 2015	-4	15.8	25	-17.9	8.8	23	13.7%	13.90 [6.74, 21.06]
Schilcher 2017	-9	7.2	29	-4.8	11.2	27	15.3%	-4.20 [-9.17, 0.77]
Sluimer 2006	-14.3	12.5	40	-14.9	12.3	40	15.0%	0.60 [-4.83, 6.03]
Subtotal (95% CI)			151			171	57.6%	0.98 [-6.83, 8.79]
Heterogeneity: Tau² = 53.36; Chi² = 19.68, df = 3 (P = 0.0002); I² = 85%								
Test for overall effect: Z = 0.25 (P = 0.81)								
3.1.4 change 2 year(%)								
Salemyr 2015	-2.5	18.2	24	-20.6	9.8	23	12.9%	18.10 [9.79, 26.41]
Schilcher 2017	-9.5	11.4	28	-5.7	11.3	28	14.6%	-3.80 [-9.75, 2.15]
Sluimer 2006	-13.4	13.9	40	-15.6	11.5	40	14.9%	2.20 [-3.39, 7.79]
Subtotal (95% CI)			92			91	42.4%	5.13 [-6.08, 16.33]
Heterogeneity: Tau² = 86.40; Chi² = 17.79, df = 2 (P = 0.0001); I² = 89%								
Test for overall effect: Z = 0.90 (P = 0.37)								
Total (95% CI)			243			262	100.0%	2.66 [-3.31, 8.64]
Heterogeneity: Tau² = 54.32; Chi² = 38.92, df = 6 (P < 0.00001); I² = 85%								
Test for overall effect: Z = 0.87 (P = 0.38)								
Test for subgroup differences: Chi² = 0.35, df = 1 (P = 0.55), I² = 0%								

Favours SS   Favours CS

Figure 3 Forest plot of BMD changes in Gruen zone 1.

promising.[21 24 31] Several meta-analyses have evaluated the effectiveness of SS in primary THA. Decking et al[34] reported unsatisfactory SS survival rates. Huo et al[25] reported that SS might achieve the same clinical and radiological outcomes as CS in addition to reducing thigh pain after surgery. However, limited trials were pooled for the analysis in the review due to incomplete search strategies. Subsequent studies were published recently. In this systematic review and meta-analysis, we sought to address whether, compared with CS, SS in primary THA might provide superior bone remodelling and lower revision rates with improved clinical outcomes. To the best of our knowledge, the present results derived from all the available comparative data are the first to document the differences in postoperative bone remodelling, implant

survival, complications and radiological performance between SS and CS.

However, as no clear definition of short stem exists, there are different classification systems for short stems. Gulow et al[35] divided short stems into three types according to the different anchoring principles, including (1) resurfacing endoprostheses anchoring on the epiphysis; (2) collum endoprostheses solely anchoring on the metaphysis; and (3) short collum-preserving stems anchoring on the metaphysis with short anchorage on the diaphysis. Oldenrijk et al[36] classified short stems into three categories: (1) 'collum': conical or cylindrical ultra-short stems, with complete anchorage in the femoral neck; (2) 'partial collum': partial femoral neck-sparing curved designs; and (3) 'trochanter-sparing': trochanter-sparing
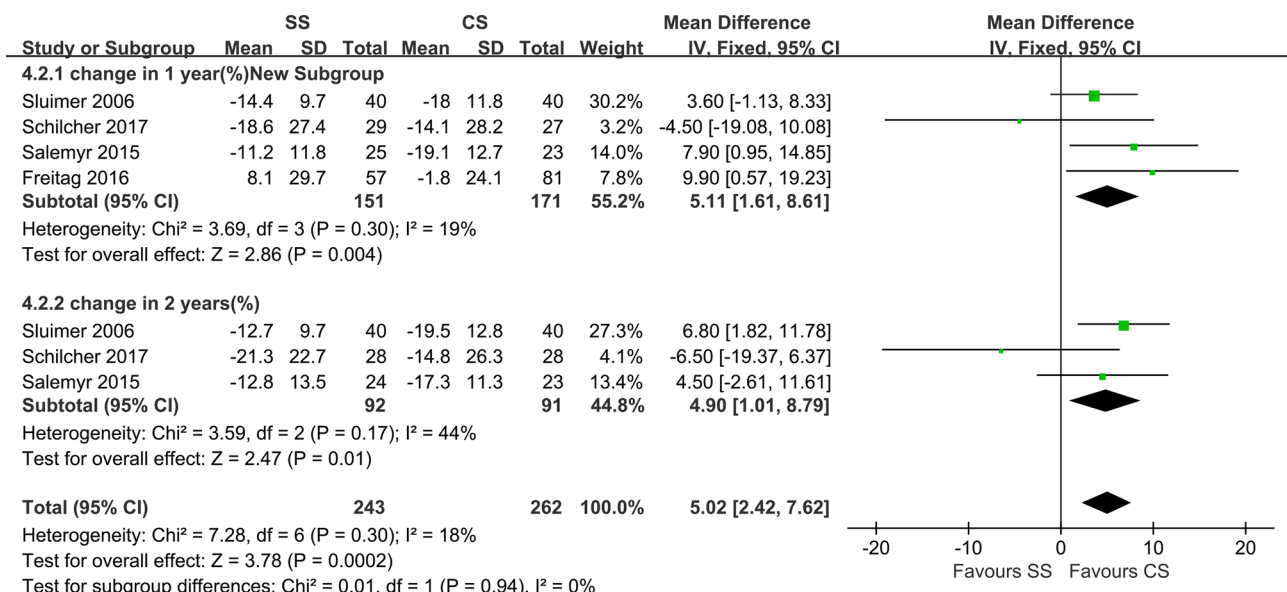
Study or Subgroup	SS Mean	SD	Total	CS Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
4.2.1 change in 1 year(%)New Subgroup								
Sluimer 2006	-14.4	9.7	40	-18	11.8	40	30.2%	3.60 [-1.13, 8.33]
Schilcher 2017	-18.6	27.4	29	-14.1	28.2	27	3.2%	-4.50 [-19.08, 10.08]
Salemyr 2015	-11.2	11.8	25	-19.1	12.7	23	14.0%	7.90 [0.95, 14.85]
Freitag 2016	8.1	29.7	57	-1.8	24.1	81	7.8%	9.90 [0.57, 19.23]
Subtotal (95% CI)			151			171	55.2%	5.11 [1.61, 8.61]
Heterogeneity: Chi² = 3.69, df = 3 (P = 0.30); I² = 19%								
Test for overall effect: Z = 2.86 (P = 0.004)								
4.2.2 change in 2 years(%)								
Sluimer 2006	-12.7	9.7	40	-19.5	12.8	40	27.3%	6.80 [1.82, 11.78]
Schilcher 2017	-21.3	22.7	28	-14.8	26.3	28	4.1%	-6.50 [-19.37, 6.37]
Salemyr 2015	-12.8	13.5	24	-17.3	11.3	23	13.4%	4.50 [-2.61, 11.61]
Subtotal (95% CI)			92			91	44.8%	4.90 [1.01, 8.79]
Heterogeneity: Chi² = 3.59, df = 2 (P = 0.17); I² = 44%								
Test for overall effect: Z = 2.47 (P = 0.01)								
Total (95% CI)			243			262	100.0%	5.02 [2.42, 7.62]
Heterogeneity: Chi² = 7.28, df = 6 (P = 0.30); I² = 18%								
Test for overall effect: Z = 3.78 (P = 0.0002)								
Test for subgroup differences: Chi² = 0.01, df = 1 (P = 0.94), I² = 0%								

Favours SS   Favours CS

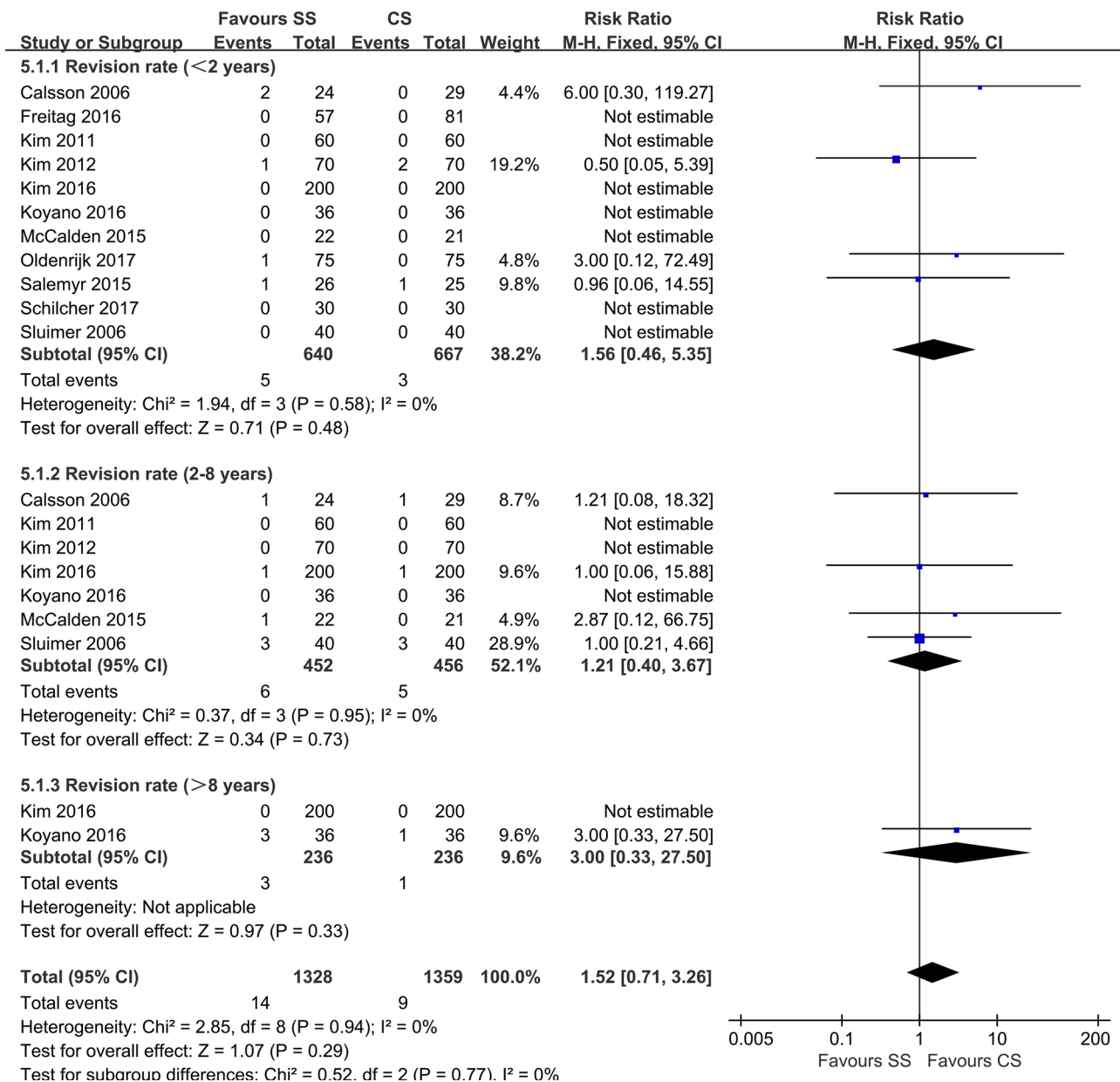**Figure 4** Forest plot of BMD changes in Gruen zone 7.

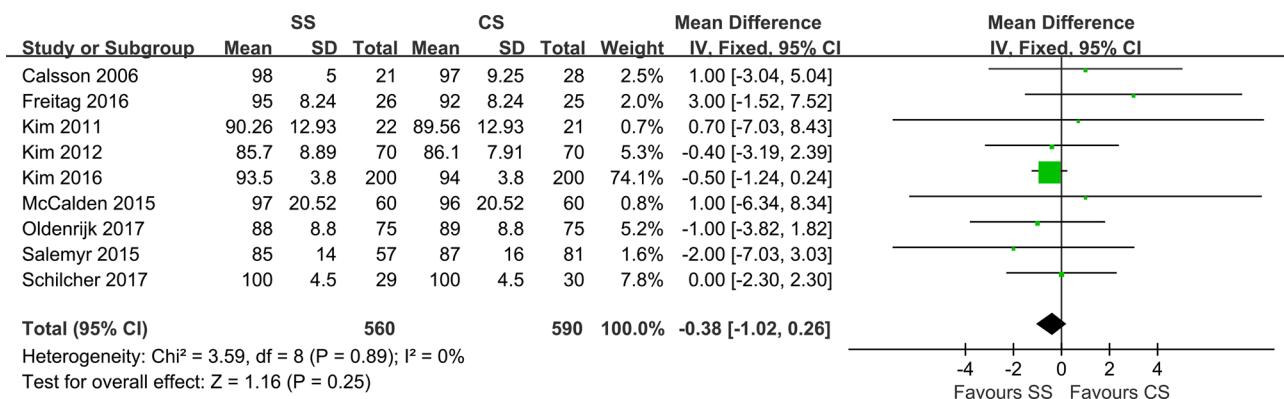**Figure 5** Forest plot of revision rates.

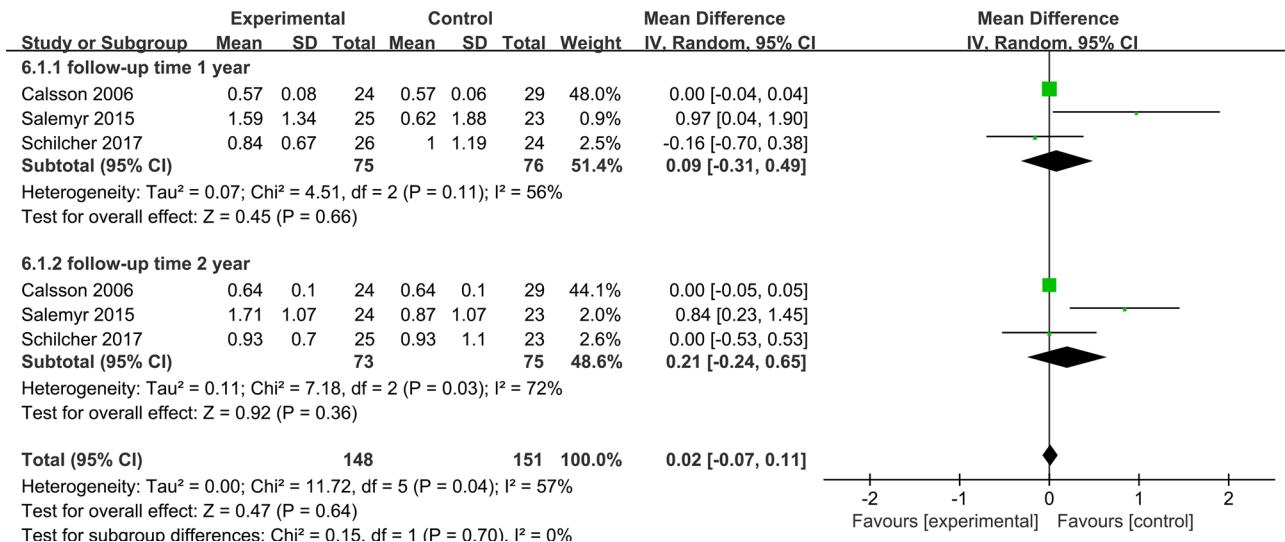**Figure 6** Forest plot of Harris Hip Scores.

Figure 7 Forest plot of maximum total point motion.

but not neck-sparing, with a shortened tapered stem. The differentiation of short stems within a single classification system was clear. However, there was little difference between the short stem of the metaphyseal anchorage (partial neck preserving) group and shortened standard stems according to the classification principles mentioned above. According to the classification system of Khanuja et al,[14] which categorised SS into four categories based on fixation principles and the location of proximal loading, metaphyseal anchorage short stems were those that retained the femoral neck by using partial collum short stems, with a curved or angulated distal end of the stem contacting the proximal lateral cortex and potentially improving biomechanical reconstruction. Shortened standard stems were similar to conventional, proximally porous-coated tapered designs with a shorter length or a reduced distal end of the stem, which were designed for proximal stress transfer. This type of stem is rarely neck-preserving and often extends to the upper diaphysis. With their tapered-wedge design and proximal porous coating, these stems achieve fixation proximally.[37]

In terms of BMD changes, significant bone loss of the proximal femur was found in both groups compared to before surgery, which was consistent with the results of previously reported studies.[38–40] The pooled results of the meta-analysis of four studies with BMD changes revealed that SS and CS were comparable for G1 at both the 1- and 2-year follow-ups. However, a significant decrease was found for G7 at these two different time points. Some studies[21 24 30] provided only comparisons between the endpoints and 1 week postoperatively and no comparison was performed in other studies. We therefore excluded these studies from the analysis. Although only two trials in the analysis found significantly different BMD changes between the groups for G7, significant differences were also found in the previous studies.[23 24] Because bone remodelling after femoral implantation is most dynamic within the first postoperative year,[41] which is also the period during which most periprosthetic BMD changes

occur after femoral stem implantation,[42 43] the short-term (>1 year) evaluation of BMD changes might objectively ascertain bone remodelling after THA.

Longer-term follow-up showed that BMD increased in G1 and that it decreased less in G7 at 1 year postoperatively in SS subjects when compared with the decreased BMD observed for both G1 and G7 in CS subjects,[44] which might lead to further proximal femoral bone loss in the CS group with longer-term follow-up. These findings suggested that, compared with CS, SS may achieve superior biomechanical loading, more pronounced proximal load transfer to reduce stress shielding and may preserve more bone stock in primary THA to some extent. Because the BMDs of other zones were insufficient to evaluate bone remodelling of the distal femur, distal loading after implantation remains unclear, considering that migration and fracture might occur should loading become excessive,[45 46] although some researchers[34] observed decreased bone density in other zones. The BMD values in some of the included studies varied, which might have been due to different measurements and varied patient positioning when the assessments were performed. Additionally, Jahnke et al[26] found that BMD changes were related to gender and age and that greater BMD changes occurred in men and older participants. However, we observed no pronounced differences in our analysis. Although the reduction in proximal BMD reduces the area of implant-bone support, potentially leading to late failure or periprosthetic fatigue fractures,[47] whether mid-term bone remodelling necessarily reflects long-term consequences remains unknown.

According to Oldenrijk et al, most of the short stems included in our review were trochanter-sparing stems.[19 20 23 24 30–32] One was classified as a collum stem, and another one as a partial collum stem. However, BMD values were available only for the trochanter-sparing stems included in our review. We tried to individually assess each short stem of the seven studies, which reported the BMD values of different zones. Three studies evaluated

the BMD changes of the Proxima stem (DePuy), and the others reported on Fitmore (Zimmer), Omnifit-HA1090 (Osteonics), Super Secur-Fit (Stryker) and Taperloc Microplasty (Biomet). However, limited data and variations in follow-up did not allow for further assessments.

Some non-randomised studies have evaluated BMD changes with DEXA. Lerch et al[48] examined BMD changes following Metha short -stem implantation, and the result showed that compared with baseline values measured immediately postoperatively, there was about a 10% periprosthetic bone loss in G7 after 1 year, which was consistent with the result of another study performed by Jahnke et al.[26] However, Lerch et al reported that a regain of BMD in the G7 was found 2 years post-surgery. Chen et al[49] performed a retrospective BMD analysis following implantation of the Mayo short stem and indicated that compared with the contralateral hip, the decrease (14.4%–17.9%) in the BMD was significant in G1, G6 and G7 and was much less apparent in other zones. Lazarinis et al[50] carried out a prospective cohort study of collum femoris-preserving stems, and DEXA after 1 year showed a substantial loss of the BMD of between 13% and 31% in G7, G6 and G2. Nevertheless, some research has indicted contradicting results. A prospective study evaluated the periprosthetic BMD change of the Fitmore stem and Trabecular Metal Primary stem, and a lower periprosthetic bone loss was observed in all Gruen zones.[51] Moreover, a retrospective study of within 10-year follow-ups found no significant difference in the periprosthetic BMD between short anatomical stems and metaphyseal anchored short stems. The bone mineral density significantly increased in G1 at each follow-up but slightly decreased in G7 in both groups. However, the results of these studies were insufficient to provide a power of comparability, as they were non-randomised or lacked a direct comparison between short and conventional stems.

Revision rates were comparable regardless of femoral stem length. Four studies reported no revisions observed during the research period and the remaining studies were pooled for the analysis with an average follow-up of 4.1 years. The revision rate was similar between the groups and was within the range of previous studies.[1 52] Therefore, based on the available evidence, SS was as durable as CS according to short-term to mid-term follow-up in primary THA. The reasons for the revision found in the included studies encompassed recurrent dislocation, loosening, periprosthetic fracture, idiopathic osteonecrosis, painful iliac pseudotumour and deep periprosthetic infection. Subgroup analysis was performed based on revision for the reasons of periprosthetic fracture and loosening, and the results were consistent in the pooled analysis. Thus, we concluded that both SS and CS might achieve similar revision rates at the early stage after primary THA. The revision rate was high in one trial with two of the revisions due to aseptic loosening that occurred within 2 years, and a third undertaken for femoral neck resorption. The short-stem femoral prostheses of this study were metaphyseal loading, threaded, cylindrical designs with

a collar, which led to a noted increase in strains on the lateral side of the greater trochanter and assessment of the risk of failure.[53] Notably, this type of stem is no longer available. Towle et al[54] observed a higher rate of implant revision in men after primary THA compared with that in women. However, limited data were available to evaluate the gender-specific risk of revision in our study.

Significant HHS improvement was found for both types of stems compared with the preoperative values. Increased HHS may be realised shortly after surgery and maintained at a high level. Additionally, strong evidence indicated no difference between SS and CS groups, which was consistent with a previous meta-analysis[25] and cohort studies with long-term follow-ups.[55 56] However, we were unable to evaluate other factors that might have had a potential influence, and whether longer-term clinical performance is maintained warrants concern. MTPM measured by radiosteromeric analysis) may critically assess stem micromovement.[55 56] Although the results of the analysis revealed no significant difference between the two stems at 1 year and 2 years of follow-up, a concern exists that more migration might arise in the CS group in the long term, which might predict implant loosening.

The most common complications related to surgery reported in the included studies were recurrent dislocation[20 21 29 31]; venous thromboembolism, including deep vein thrombosis and pulmonary embolism; and deep periprosthetic infection.[19 31] Reduced thigh pain in SS was reported in four studies,[19 23 24 30] although the aetiology of thigh pain remains unclear and whether the occurrence of thigh pain is related to periprosthetic loosening remains unknown. Rehabilitation programmes and bearing surfaces varied in the included studies. Ceramic-on-ceramic bearing surfaces of the prostheses were reported in most included studies; only one study reported a ceramic-on-polyethylene bearing,[22] with no increased migration observed.[57] Most studies reported full weight-bearing after surgery using two crutches. Others included full weight-bearing after 2 days, partial (50%) weight-bearing and full weight-bearing postoperatively for 6 weeks. Early research considered it a crucial factor for early fixation. However, a recent study indicated that early full weight-bearing and partial-bearing rehabilitation did not have a significant impact on clinical outcomes and complications in THA.[58] A radiolucent line was reported in only two studies. McCalden et al[32] reported one subject with a radiolucent line in the SS group and revision surgery was performed. However, 14 cases of a radiolucent line adjacent to the proximal cranial fixation region of the femoral component were reported in the SS group without detailed descriptions in another report. Calsson et al[29] used a Type-2C stem design, which is no longer available. Despite potential improvement in proximal loading, stress shielding in the calcar and greater trochanter regions remains a challenge at short- to intermediate-term follow-up for most designs. Although stress shielding was observed in both groups in some studies, we were unable to determine whether SS might cause a higher rate of stress shielding.

Interestingly, substantial differences in femoral morphology were observed among patients in different studies using the Dorr classification,[59] which was reported in limited studies. Of these studies, five trials[19 21 23 31 32] excluded participants who had a type C femur. Schilcher et al[31] found a significant effect of Dorr type on prostheses migration. More migration was observed in the CS group, particularly in type A femurs. However, two studies[24 30] that included patients with type C femora achieved similar clinical and radiological results in that subtype compared with other femoral types by using Proxima SS. Thus, more trials are needed to determine whether SS might obtain similar outcomes in patients with different types of femora.

Strength and limitations

The present results derived from all available comparative data are the first to document the differences in postoperative bone remodelling, implant survival, complications and radiological performance between SS and CS. Our study has several limitations. First, sample size heterogeneities existed and the moderate methodological quality of some of the included studies might have biased the meta-analysis. Second, although the most recent evidence regarding the use of SS and CS in primary THA were provided in our study, the average follow-up length of 3.9 years (range, 0.115–11.8 years) was relatively short for evaluating the outcomes of femoral prostheses. Third, in addition to the different surgical indications, such as osteoarthritis, osteonecrosis and femoral fractures, that were included, basic parameters, such as patient age, gender and BMI, which may influence bone remodelling progression and stress shielding, varied in the studies, although comparable performance characteristics were observed among younger patients in the SS group and CS groups.[24] Fourth, in addition to the materials, the stem designs were inconsistent across the studies. However, the effects of the lateral flare design and the extent and type of surface coating for bone conservation in primary THA have not been fully defined. Moreover, based on the limited data, we only evaluated bone remodelling of trochanter-sparing SS, while other categories were not assessed and require future study. Finally, although reasons for revision plans were evaluated in included studies, details of the failures were not known. We only evaluated the revision rates for any reason, without subgroup analysis of the different mechanisms, and we cannot make any statements regarding patient satisfaction. Despite the limitations, the present meta-analysis demonstrated that compared with CS, SS might achieve superior bone remodelling for proximal fixation and bone preservation, with similar revision rates and functional outcomes.

CONCLUSION

In conclusion, compared with CS, SS showed similar prosthesis survival rates, functional outcomes and migration in primary THA. However, SS may achieve superior bone remodelling and preserve more proximal bone stock in the short term. Additionally, SS may be applied to any type of femoral morphology. Considering these outcomes, the use of SS in primary THA may have several subtle clinical advantages over CS. However, because of the short-term follow-up and stem variation in our study, more high-quality RCTs are needed to further identify the optimal femoral prostheses for primary THA.

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