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Review article

OXFORD

Influence of less invasive hip preservation surgery on subsequent hip arthroplasty for osteonecrosis of the femoral head

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ABSTRACT

The purpose of this study was to evaluate the outcomes of total hip arthroplasty (THA) following less invasive hip-preserving procedures (LIHPs) and present a critical overview of the literature to aid in better result interpretation. The search time was from the establishment of the database to September 2021, and the outcome indicators were extracted and analyzed by Cochrane Collaboration Review Manager software (RevMan version 5.4). Finally, 10 articles were included in this meta-analysis by searching Chinese databases and English databases. Three of them were published in Chinese, and the remaining studies were published in English. LIHP was further divided into the tantalum rod implantation group and the non-tantalum rod implantation group. The results showed that prior tantalum rod implantation increased the difficulty of conversion to THA, which was reflected mainly in the longer operative time [weighted mean difference (WMD) = 24.50, 95% confidence interval (CI) = 14.09–34.91, $P < 0.00001$] and greater intraoperative blood loss (WMD = 114.74, 95% CI = 33.52–195.96, $P = 0.006$), while no significant difference was found between the non-tantalum rod implantation group and the control group. Simultaneously, easier intraoperative fracture [odds ratio (OR) = 5.88, 95% CI = 0.93–37.05, $P = 0.06$] and stem malalignment (OR = 4.17, 95% CI = 1.18–14.71, $P = 0.03$) in the LIHP group tended to be observed than in the control THA group. However, there was no significant difference in cup anteversion and inclination angle, ectopic ossification, postoperative Harris Hip Score and survivorship between the LIHP group and the control group. Although LIHP increased the difficulty of the conversion to THA, it does not detrimentally affect the clinical results of subsequent THA in the mid-term follow-up.

INTRODUCTION

Osteonecrosis of the femoral head (ONFH) is a progressive disabling and refractory bone joint disease that mainly affects young and middle-aged adults [1]. It is a male-dominant disease, with a 3-fold higher incidence of ONFH in men than in women, and bilateral hip involvement is common (approximately 75%) [2]. According to epidemiological reports, the incidence rate of ONFH has been increasing worldwide, and the unreasonable and excessive steroid use has exacerbated the trend of young age [3, 4]. The pathogenesis of ONFH has yet to be fully clarified, and the treatments are mainly toward providing symptomatic management [5]. Total hip arthroplasty (THA) is the most common surgical procedure for patients with ONFH [6]. However, it is not an ideal choice for young patients because they will face the risk of revision in the future and the risk of failure in such operations is high due to the loss of bone mass [7]. Hence, this has led to the development of hip preservation surgery in the treatment of young patients with ONFH [8].

Currently, early diagnosis of ONFH has become possible with the development of diagnosis technology, which provides more opportunities for hip preservation surgery. The methods of hip-preserving operation in clinical, such as core decompression (CD), non-vascularized or vascularized bone grafting, rotational osteotomies and tantalum rod implantation, have achieved a certain effect during the early stages of ONFH based on previous studies [9–11]. However, the success rate of these preservation treatments listed above was not as effective as expected and was significantly reduced with the advancement of the disease stages, i.e. after any collapse of the femoral head [8, 11–13]. In a meta-analysis of CD with the insertion of a tantalum rod in ONFH treatment, at a mean follow-up of 26.97 months, 24.63% of the included hips underwent a hip arthroplasty [14]. THA

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is currently recognized as an end-stage treatment for hip joint disease, so for patients who receive THA after failed hip preservation surgery, we should consider whether prior hip preservation surgery has a detrimental effect on subsequent THA for ONFH.

Hip preservation surgery tends to emphasize on mechanical repair, giving consideration to biological repair, by changing the anatomy of the proximal femur. Therefore, surgeons need to account for these deformities when performing a conversion THA. Lim *et al.* [15] classified the surgery as less invasive hip-preserving procedures (LIHPs) or more invasive hip-preserving procedures (MIHPs) depending on the technical requirement and invasiveness of the procedure. Wang *et al.* [16] considered CD with or without any supporting structure, including cement, bone graft or tantalum rods as one class of operations, which had less invasiveness, and performed a meta-analysis on this basis. Thus, hip preservation surgery was divided into two groups in our study: the LIHPs including CD with or without any supporting structure and the MIHPs including rotational osteotomy or vascularized bone grafting. The validity of MIHP such as transtrochanteric rotational osteotomy for the collapsed ONFH in early to late stage has been confirmed [17]. However, surgical complexity and complications have likely contributed to the lower utilization of MIHP, while LIHP was widely available for clinical use, especially for patients with Ficat 1 and 2 or Association Research Circulation Osseous (ARCO) Stages I and II [4].

To our knowledge, earlier meta-analysis literature suggested that subsequent THA after the prior transtrochanteric rotational osteotomy and pelvic osteotomy had a comparable clinical result compared with primary THA [18, 19]. Wang *et al.* [16] performed a meta-analysis with respect to the effect of prior CD on subsequent THA for ONFH; however, pooled analyses of several valuable outcome parameters were unavailable due to the limited number of trials. Given the significant role of LIHP in clinical usage, it is essential to get deeper insights into the effect of LIHP on subsequent THA. In this study, a thorough search was conducted to retrieve trials of subsequent THA after LIHP. This paper will provide updated evidence on the operative time, operative blood loss, radiological parameters, complications and clinical outcomes.

MATERIALS AND METHODS

Search strategy

This study followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) [20]. Approval or patient consent was not necessary because all the analyses were performed on the basis of previously published studies. The search language was restricted to Chinese and English, and the reference of the included studies was also searched. Chinese databases including China national knowledge infrastructure (CNKI), Wan-Fang databases and China Science and Technology Journal Database (VIP), and English databases, including PubMed, Embase and Cochrane library were searched by computer from the inception of each database to 27 September 2021. The following search terms were used: ('arthroplasty, replacement, hip' or 'total hip arthroplasty' or 'THA' or 'hip prosthesis implantation' or 'hip replacement arthroplasty'), ('core decompression' or 'decompression' or 'bone grafting' or 'grafting, bone' or 'tantalum implant' or 'tantalum rod implantation' or 'trabecular meta implant' or 'metal implant') and ('femur head necrosis' or 'femoral head necrosis' or 'osteonecrosis of the femoral head' or 'avascular necrosis of femur head'). All identified articles were individually examined to check for inclusion.

Eligibility criteria

The literature was screened according to the following inclusion criteria: (i) study design included case–control, retrospective and prospective; (ii) LIHP included CD, non-vascularized autogenous bone graft or allograft and tantalum rod. In this study, we only included the LIHP, including CD with or without any supporting structure. The MIHP, including vascularized bone grafts and transtrochanteric rotational osteotomy, was not included due to the significant invasiveness of the procedure. Duplicate publications and articles, reviews, letters, comments and meeting proceedings were also excluded.

Study selection and data extraction

For the inclusion decision, two investigators independently evaluated the eligibility of studies. If they both agreed, the study would be included in this present study, and any inconsistencies were resolved with the consensus of all investigators.

Design information, baseline population characteristics (age, sex, sample size and country), surgical procedure, body mass index and follow-up period after the THA from all included studies were stratified into a standardized evidence table. Parameters of the outcomes for the meta-analysis were operative time, operative blood loss, complications, radiological parameters and clinical outcomes.

Quality assessment

Two independent reviewers evaluated the included studies based on the items of the modified Newcastle–Ottawa Scale (NOS) [21], comprising patient selection, study group comparability and outcome assessment; six or more stars were considered to be a study of high quality.

Statistical analysis

The meta-analysis and statistical analysis were performed using Cochrane Collaboration Review Manager software (RevMan version 5.4), with $P < 0.05$ set as the statistically significant threshold. For continuous data with SD, meta-analysis was performed to calculate the weighted mean difference (WMD) with 95% confidence intervals (CIs). When comparing the incidence of dichotomous data, such as revision or complications, we calculated relative risk (RR) with a 95% CI for each outcome. Statistical heterogeneity was assessed based on I^2 using a standard χ^2 test. When $I^2 > 50\%$, significant heterogeneity was assumed, and a random-effects model was applied for the meta-analysis. A fixed-effects model was applied in the absence of significant heterogeneity. For studies that reported continuous variables with ranges without the SD, we conducted authors for additional information or estimated the SD using the Walter method [22]. Subgroup analysis was applied for the outcomes based on the type of hip-preserving surgery, and sensitivity analysis was also conducted. The subgroup can be broadly divided

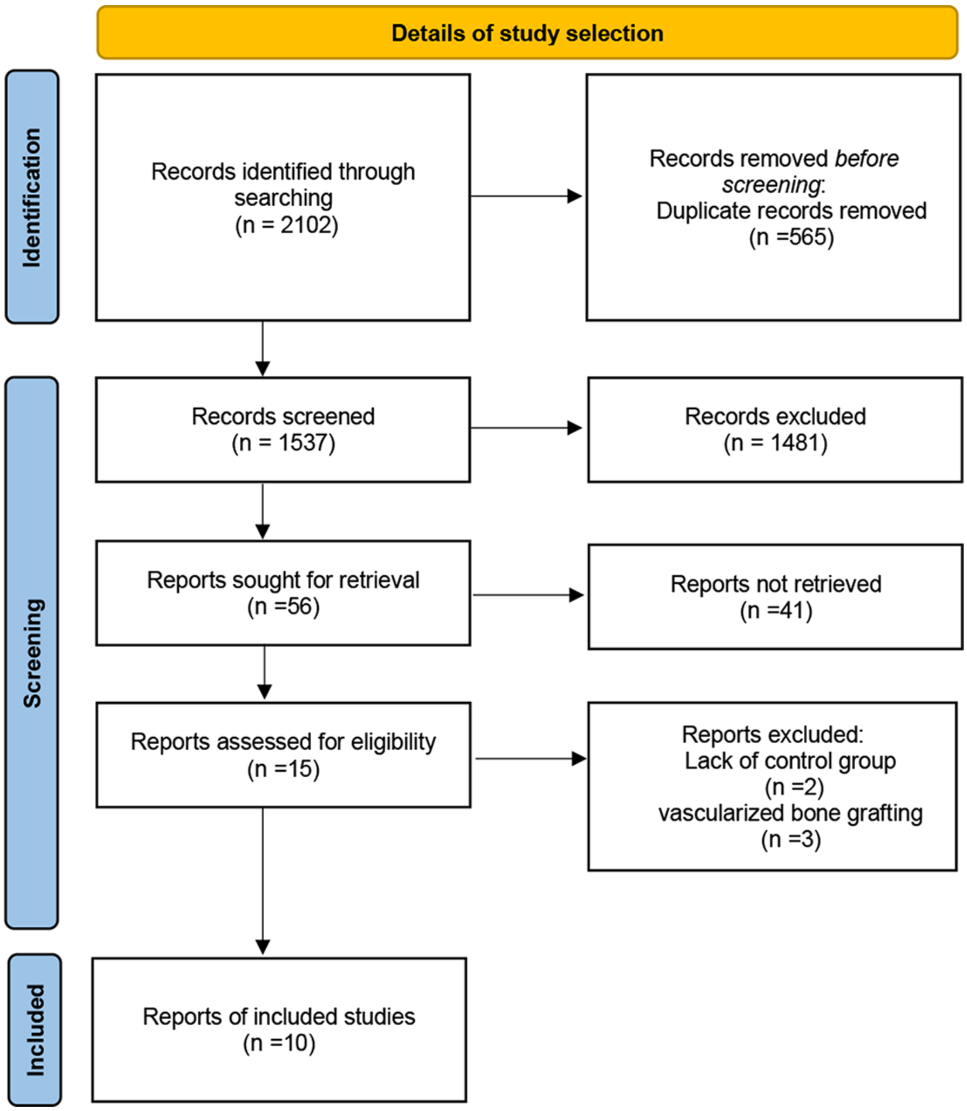

Fig. 1. Flowchart of the literature search and study inclusion.

into two groups: tantalum rod implantation and non-tantalum rod implantation (including non-vascularized bone grafting or cementing).

RESULTS

Search results and characteristics

A total of 2012 studies were identified by the search strategy. Of those articles, 565 studies were excluded because of duplication. Then, 1481 studies were excluded by title and abstract screening. Of the remaining 56 articles, 41 articles were excluded by reviewing the full text. A total of 10 retrospective cohort studies met inclusion criteria, and details of the study selection are shown in Fig. 1. Three of them [23–25] were published in Chinese, and the remaining studies were published in English. See Tables I and II for detailed information on the included studies.

Quality assessment

The NOS was used to evaluate the eligibility of included studies, and high quality was assigned when the NOS score was ≥7. The three sections of the NOS (selection, comparability and outcome) were used to score the included studies, and details are shown in Table II.

Primary results of meta-analysis

Operative time

Six articles [15, 23, 25, 27, 29–31] reported about the data of operative time. The heterogeneity ($I^2 = 95\%$) was significant; therefore, the random-effects model was used. After the quantitative analysis, operative time was longer in the LIHP group than in the primary THA group (WMD = 16.32, 95% CI = 6.72–25.93, $P = 0.0009$). A subgroup analysis of five articles [25, 27, 29–31] showed that the difference in operative time between THA with previous tantalum rod implantation and the primary THA group was significant (WMD = 24.50, 95% CI = 14.09–34.91, $P < 0.00001$). While a subgroup analysis of three articles [15, 23, 31] showed that there was no significant difference in operative time between the non-tantalum implantation group and the control group (WMD = 3.15, 95%

Table I. ***Basic characteristics of the included studies***

Authors	*Group*	*Sample size (hips)*	*Gender (M/F)*	*BMI*	*Age (years)*	*Follow-up (months)*	*Interval (months)*
Lim SJ [15]	CD cement	23	16/7	NR	40 ± 10	55 ± 33	43(4–137)
	Control	39	23/9	NR	43 ± 10	57 ± 34	–
Issa K ① [26]	CD	19	NR	30 (17–45)	45 (18–74)	67 (32–107)	20(6–56)
Issa K ② [26]	Bone grafting	29	NR	25 (18–44)	38 (18–81)	75 (13–122)	27(5–122)
	Control	121	NR	26 (15–42)	41 (12–71)	77 (38–124)	–
Lee GW [27]	Tantalum rod	8	6/0	23.7 (20.5–25.6)	36.3 (32–39)	39.8 (36–57)	NR
	Control	16	12/0	22.8 (18.8–27.7)	36.6 (32–39)	42.6 (38–57)	–
Olsen [28]	Tantalum rod	21	12/9	NR	37(18–53)	50.4(24–72)	26(6–72)
	Control	21	12/9	NR	40(18–58)	NR	–
Cheng Q [29]	Tantalum rod	39	26/5	25.2 (22.3–26.4)	49.3(36–64)	88.8(60–120)	33.1(16–63)
	Control	40	26/7	24.6 (21.5–25.6)	43.2 (37–64)	88.8(60–120)	–
Chu YM [24]	Bone grafting	27	19/8	27.9 ± 4.5	43.7 ± 14.7	46.4 ± 9.6	63.6
	Control	42	31/11	26.4 ± 3.7	45.9 ± 13.3	49.8 ± 9.2	–
Cai J [23]	Bone grafting	34	20/11	NR	52(42–65)	29.3	58.8
	Control	41	23/12	NR	50.5(34–64)	28.4	
Ma J [30]	Tantalum rod	34	21/11	24.9 ± 4.2	43.6 ± 7.6	64.1 ± 14.7	64.1 ± 14.7
	Control	32	16/9	25.3 ± 4.2	44.0± 10.7	59.4 ± 9.7	–
Zuo W ① [31]	Tantalum rod	30	NR	24.05 (17.6–31.2)	41(21–60)	64 (52–88)	31(5–66)
Zuo W ② [31]	Bone grafting	30	NR	23.59 (18.6–30.2)	42 (26–65)	59 (49–91)	39(3–77)
	Control	30	NR	25.45 (17.9–37.5)	41 (23–63)	62 (54–85)	–
Chu YM [25]	Tantalum rod	44	29/15	25.92 ± 3.42	43.7 ± 14.7	37.91 ± 7.18	NR
	Control	42	31/11	25.24 ± 3.68	45.9 ± 13.3	37.91 ± 7.18	–

M: male; F: female; NR: not reported; ① and ②: different subgroups from a study.

Table II. ***NOS and basic information of the included studies***

Study	*Year of publication*	*Year of surgery*	*Country*	*Study design*	*NOS*			*Score*
					Selection	*Comparability*	*Outcome*	
Lim SJ [16]	2008	1995–2004	Korea	RCS	***	**	***	8
Issa K [22]	2014	2001–2010	American	RCS	***	**	***	8
Lee GW [23]	2016	2010–2011	Korea	RCS	***	**	***	8
Olsen [24]	2016	2002–2013	Canada	RCS	***	**	***	8
Cheng Q [25]	2018	2007–2012	China	RCS	***	**	***	8
Chu YM [26]	2018	2013–2015	China	RCC	**	**	***	7
Cai J [23]	2018	2010–2012	China	RCC	**	**	***	7
Ma J [28]	2019	2009–2014	China	RCC	***	**	***	8
Zuo W [29]	2020	2010–2014	China	RCC	***	**	***	8
Chu YM [30]	2020	2013–2017	China	RCS	***	**	***	8

RCC: retrospective case–control study; RCS: retrospective cohort study; * represents one score point.

CI = −3.46 to 9.75, $P = 0.35$), which hints that tantalum rod implantation may be the leading cause for longer operative time (Table III).

Intraoperative blood loss

Six articles [15, 23, 25, 29–31] reported about the intraoperative blood loss during THA. There was significant heterogeneity ($I^2 = 95\%$); therefore, the random-effects model was used. The pooled result indicated a trend toward more intraoperative blood loss in the subsequent THA group compared with the primary THA group (WMD = 68.96, 95% CI = 11.90–126.02, $P = 0.02$). A subgroup analysis of four articles [25, 29–31] showed that there was a significant difference in intraoperative blood loss between THA with previous tantalum rod implantation and the primary THA group (WMD = 114.74, 95% CI = 33.52–195.96, $P = 0.006$). While a subgroup analysis of three articles [15, 23, 31] showed that the significant difference in intraoperative blood loss between the non-tantalum implantation group and the control group was not significant (WMD = 0.82, 95% CI = −28.32 to 29.96, $P = 0.96$), which also hints that tantalum rod implantation may be the leading cause for larger intraoperative blood loss during conversion THA (Table III).

Intraoperative fracture

Three articles [15, 27, 31] reported about the rate of intraoperative fracture. The results of subgroup analysis showed that two studies reported intraoperative fracture data of the non-tantalum implantation group [odds ratio (OR) = 5.62, 95%

Table III. ***Summary results of meta-analysis***

Outcome indicators	*Subgroup*	*Number of comparison studies*	*Results of meta-analysis* MD [95% CI]	*P-value*	I^2 (%)
Operative time	Non-tantalum	3 [15, 23, 31]	3.15 [−3.46, 9.75]	0.35	71
	Tantalum	5 [25, 27, 29–31]	24.50 [14.09, 34.91]	<0.00001	90
	Total	8	16.32 [6.72, 25.93]	0.0009	95
Intraoperative blood loss	Non-tantalum	3 [15, 23, 31]	0.82 [−28.32, 29.96]	0.96	0
	Tantalum	4 [25, 29–31]	114.74 [33.52, 195.96]	0.006	93
	Total	7	68.96 [11.90, 126.02]	0.02	91
Intraoperative fracture	Non-tantalum	2 [15, 31]	5.62 [0.62, 50.89]	0.12	0
	Tantalum	1 [27]	6.60 [0.24, 181.64]	0.26	0
	Total	3	5.88 [0.93, 37.05]	0.06	0
Ectopic ossification	Non-tantalum	2 [15, 24]	2.24 [0.48, 10.51]	0.31	0
Stem malalignment	Non-tantalum	2 [15, 24]	5.51 [1.24, 24.45]	0.02	0
	Tantalum	1 [25]	1.95 [0.17, 22.37]	0.59	~
	Total	3	4.17 [1.18, 14.71]	0.03	0
Cup anteversion angle	Non-tantalum	1 [31]	0.36 [−0.67, 1.39]	0.50	~
	Tantalum	5 [25, 27, 29–31]	−0.25 [−0.84, 0.34]	0.40	0
	Total	6	−0.10 [−0.64, 0.41]	0.70	0
Cup inclination angle	Non-tantalum	3 [15, 23, 31]	0.36 [−0.57, 1.29]	0.45	0
	Tantalum	5 [25, 27, 29–31]	0.62 [−0.13, 1.37]	0.11	0
	Total	8	0.52 [−0.07, 1.10]	0.08	0
Postoperative HHS	Non-tantalum	5 [15, 23, 24, 26, 31]	0.44 [−0.22, 1.10]	0.19	7
	Tantalum	5 [25, 27, 29–31]	−0.07 [−0.59, 0.45]	0.78	59
	Total	10	0.12 [−0.29, 0.53]	0.56	42
Survivorship	Non-tantalum	2 [15, 26]	1.72 [0.37, 7.92]	0.49	0
	Tantalum	1 [31]	0.32 [0.01, 8.24]	0.49	~
	Total	3	1.18 [0.31, 4.54]	0.81	0

CI = 0.62–50.89, $P = 0.12$], and one study reported intraoperative fracture data of the tantalum implantation group ($P = 0.26$). However, summary data meta-analysis showed that the risk of intraoperative fracture was higher in the LIHP group compared with the primary THA group, but the difference was not statistically significant (OR = 5.88, 95% CI = 0.93–37.05, $P = 0.06$) (Table III).

Ectopic ossification

Two studies [15, 24] of the non-tantalum implantation group reported about the rate of ectopic ossification. The results of fixed-effects model meta-analysis showed that there was no significant difference in the rate of ectopic ossification between the non-tantalum implantation group and the control group (OR = 2.24, 95% CI = 0.48–10.51, $P = 0.31$) (Table III).

Varus or valgus femoral stem

Three articles [15, 24, 25] provided data to calculate OR and associated 95% CI of the varus or valgus femoral stem rate between the LIHP group and the control group. The results of subgroup analysis showed that two studies reported stem malalignment data of the non-tantalum implantation group (OR = 5.51, 95% CI = 1.24–24.45, $P = 0.02$), and one study reported stem malalignment data of the tantalum implantation group ($P = 0.59$). Summary data meta-analysis showed that the rate of the stem malalignment in the subsequent THA group was significantly higher than that in the primary THA group (OR = 4.17, 95% CI = 1.18–14.71, $P = 0.03$) (Table III).

Cup anteversion and inclination angle

Five articles [25, 27, 29–31] provided enough data to assess the cup anteversion angle in the LIHP group and the control group. The fixed-effects model was used for no significant heterogeneity ($I^2 = 0\%$). Pooling the data showed that there was no significant difference in cup anteversion angle between the LIHP group and the control group (WMD = −0.10, 95% CI = −0.61 to 0.41, $P = 0.70$). The subgroup analysis also did not deliver any positive results (Table III).

Seven articles [15, 23, 25, 27, 29–31] provided enough data to assess the cup inclination angle in the LIHP group and the control group. The fixed-effects model was used for no significant heterogeneity ($I^2 = 0\%$). The pooled outcome estimates of these studies suggested that previous LIHP did not significantly influence the cup inclination angle (WMD = 0.52, 95% CI = −0.07 to 1.10, $P = 0.08$). The subgroup analysis also did not deliver any positive results (Table III).

Postoperative Harris Hip Score

Nine articles [15, 23–27, 29–31] reported about the postoperative Harris Hip Score (HHS) at the final follow-up. The fixed-effects model was used for no significant heterogeneity ($I^2 = 0\%$). There was no significant difference in the postoperative HHS between the two groups at the final follow-up (WMD = 0.12, 95% CI = −0.29 to 0.53, $P = 0.56$). The subgroup analysis also did not deliver any positive results (Table III).

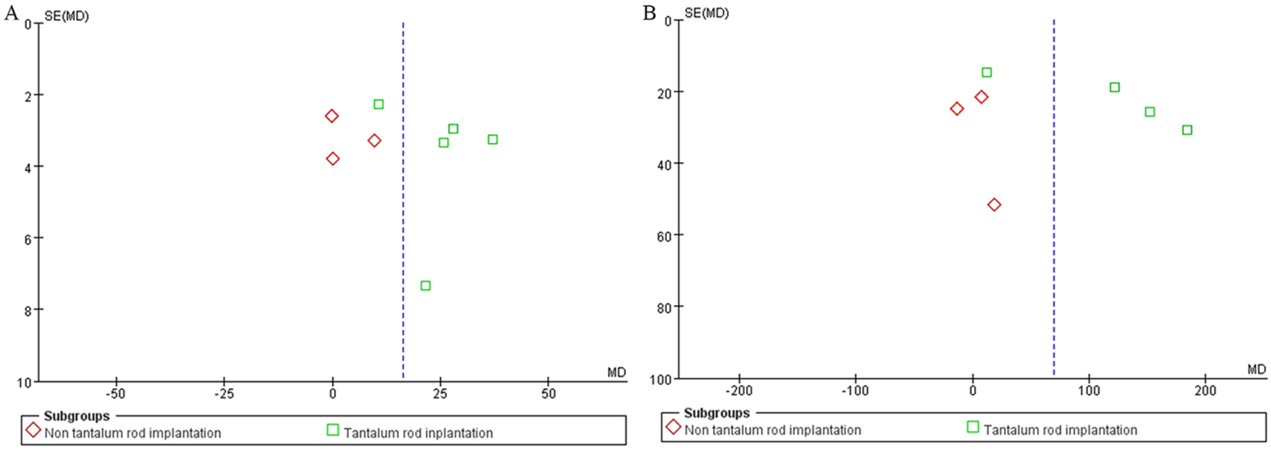

Fig. 2. (A) Funnel plot for operative blood loss. (B) Funnel plot for operative time. An asymmetry was exhibited in the funnel plot, which reflected the publication bias.

Survivorship

Three articles [15, 26, 31] reported about the rate of revision. In total, three revisions occurred in the subsequent THA group (3/101) (two separate revisions for acetabular loosening at 49 and 65 months and one revision for periacetabular osteolytic lesion at 10 years), while four occurred in the primary THA group (5/190) (three separate revisions for acetabular component loosening at 67, 81 and 92 months, one revision for periacetabular osteolytic lesion at 9 years and one revision for posterior dislocation at 2 months). The fixed-effects model was used for no significant heterogeneity ($I^2 = 0\%$). There was no significant difference in the survivorship between the two groups (OR = 1.18, 95% CI = 0.31– 4.54, $P = 0.81$) (Table III).

Sensitivity test and publication bias

We conducted a sensitivity analysis of each outcome via removing the included studies, one at a time. There was no significant difference in outcomes, indicating that the results were stable. Publication bias was evaluated through visually inspecting the funnel plot of the operative blood loss (Fig. 2A) and operative time (Fig. 2B), which indicated that the influence of publication bias on the results could be ignored.

DISCUSSION

Based on the reports in the literature, 59% of untreated asymptomatic ONFH is unlikely to escape the collapse of femoral head leading to osteoarthritis and destruction of the hip joint [32]. Most of them usually end up with THA, but LIHP treatments are tried in young patients and those with pre-collapse stages (ARCO stages I and II) whenever possible [5]. Due to this, this study systematically collected relevant clinical trials and conducted a meta-analysis to help surgeons better understand the impact of prior LIHP on subsequent THA. In this current meta-analysis, LIHP was further divided into the tantalum rod implantation group and the non-tantalum rod implantation group. On the basis of the results of our study, the presence or absence of tantalum rod implantation produced different results for conversion THA surgery. Prior CD or combined with bone grafting had no significant effect on operative blood loss and operative time, which were significantly increased by prior tantalum rod implantation. They both had no significant effect on the anteversion and inclination angle of acetabular cup. Regarding other outcome measures, prior LIHP increased the rate of intraoperative fracture and stem malalignment, but not influenced the clinical outcomes in the mid-term follow-up.

CD, one of the least-invasive procedures for ONFH, is considered to cause minimal anatomical deformation of the proximal femur, but it may compromise the structural integrity of the cancellous bone, especially in the proximal femur. Currently, CD alone is rarely used but usually combined with other materials, such as bone, tantalum rod or biologics [2, 33]. In our literature, one study reported effects of CD only on subsequent THA, and five studies reported effects of CD with bone grafting on subsequent THA. They were classified as the non-tantalum rod implantation group, and the results showed that there was no significant difference in the operative time and intraoperative blood loss between this group and the control group. As early as 1998, Mont *et al.* [34] suggested that bone grafting for ONFH will not increase the difficulty of subsequent THA surgery after failed bone grafting surgery. The results of each study included in the non-tantalum rod implantation group also supported this conclusion. Therefore, in terms of the operative time and intraoperative blood loss, there was no significant difference between the non-tantalum rod implantation group and the control group.

Regarding THA after previous implantation of tantalum rods, several studies reported longer operative time and greater operative blood loss compared with primary THA. The increases in operative time and intraoperative blood loss were related to the process of removing failed tantalum rods, and the procedure can be difficult due to bone ingrowth in the live bone area of the proximal femur. There are various methods to remove failed tantalum rods. Owens *et al.* [35] described a technical tip for removal of a well-ingrown tantalum rod. Most surgeons are likely to use this standard method to cut the rod in the femoral neck using an oscillating saw, and then a trephine was used to extract the remaining portion in an anterograde way [30, 31]. While some surgeons have used Kirschner wire or a trephine to drill holes around the tantalum rod in a retrograde method, and the tantalum rod was removed after loosening [28]. Different removal methods have different effects on operative time and intraoperative blood loss, and it could be one of the reasons that caused high heterogeneity in the tantalum rod subgroup. No matter which method is used to remove the tantalum rod, surgeons should recognize prolonged surgery duration and a large amount of bleeding, which may introduce a greater surgical risk, and should take corresponding measures, such as preparing blood products for the transfusion, when performing the THA after failed tantalum rod implantation.

Intraoperative fracture in the conversion of LIHP to THA would present difficulties for orthopedic surgeons. In this meta-analysis, there is no statistical difference in the incidence of intraoperative fracture between the LIHP group and the control group, which is consistent with the results of subgroup analysis. Our results regarding this outcome indicator were also similar to previous study [16]. However, compared with the previous study ($RR = 7.05$, $P = 0.08$) [16], we found that the trend of the intraoperative fracture rate in the conversion to THA after LIHP increased in our study ($RR = 5.88$, $P = 0.06$). The reason for this result, as reported by Owens *et al.* [35] and Zuo *et al.* [31], was that removal of tantalum rods or other supporting structures would inevitably impair the integrity of cancellous bone in the femoral neck. This founding also alerted the surgeon to careful intraoperative manipulation to avoid placing any additional stress on the cored region of the femur in the conversion to THA.

This meta-analysis showed that there was no difference in the rate of ectopic ossification, but the stem malalignment was significantly higher in the THA after failed LIHP than that in the primary THA group. As one of the hip prostheses implantations, the varus or valgus femoral stem may increase the risk of early loosening [36] and insufficiency fractures [37]. The reason of this outcome may be attributable to distortion of the proximal femur and the masked landmark after the LIHP. Whether bone grafting or tantalum rod implantation, the destruction of the lateral cortex of the greater trochanter may not be avoided. Based on this, Chu *et al.* [24] cautioned that surgeons would pay attention to the position, angle, depth and strength of femoral toothed mill, and the X-ray machine could be used to judge the position of the femoral stem when necessary.

The position and angle of the acetabular prosthesis, as the frequently used radiographic indices, is one of the essential factors that affect the mid-term and long-term efficacy of THA [38]. An incorrect placement of the acetabulum may have adverse consequences such as a high rate of hip joint dislocation, impact and artificial joint repair [39]. The result of this meta-analysis indicates that the anteversion and inclination angles of the cup were not significantly different between the LIHP group and the control THA group, which may be ascribed to hip preservation surgery not changing acetabular morphology.

In terms of clinical outcomes, HHS is the most common modality used to assess the long-term clinical results. We found that there was no significant difference in terms of postoperative HHS between the LIHP group and the control group in the 10 articles included. The subgroup analysis also did not deliver any positive results. Zuo *et al.* [31] also reported that the postoperative HHS was not significantly different between the bone impaction grafting group and the tantalum implanting group. As shown in this meta-analysis, the mean postoperative HHS in the included articles was higher than 85, indicating that these THA patients were well functioning. Of note, nearly 30% of the patients unmet expectations for THA in report [40]. Whether prior LIHP influences patient future expectation and satisfaction for THA also warrants study in the future. In addition, reducing weight bearing, such as working on crutches, using wheelchair or bed rest, tends to be needed for these patients after hip-preserving surgery, and these methods carried additional restriction in lifestyle [41]. Considering the satisfaction and quality of life of these patients were seldom mentioned by previous studies, which could induce inadequate evidence to reflect their subjective feelings after LIHP. Therefore, more clinical trials regarding the subjective feeling and satisfaction of patients following hip-preserving surgery are needed in the future to improve preoperative patient education.

In this meta-analysis, no difference was observed in the incidence of revision. In most cases, revision surgery is the result of a failed THA, which also imposes a heavy economic burden on families and societies [42]. In fact, most included studies clearly stated that there were no revision cases during follow-up in the LIHP group and the control group. Therefore, we believe that the previous LIHP is not the risk factor for the following revision.

We acknowledge that this study has several important limitations. First, the evidence presented in this study is primarily based on non-RCT reports which are more susceptible to bias, and the limited sample size may also reduce the quality of the evidence. Second, follow-up was short in duration. Without long-term clinical follow-up data (more than 10 years), it is possible that late complications have been missed. Third, the Walter method was used to estimate the SD when the data were not reported, which might influence the conclusions slightly. Furthermore, different surgeons have different surgical skills, which can also affect the outcome of patients; therefore, the results of this study cannot fully represent the therapeutic effect of subsequent THA after hip preservation surgery. However, despite these limitations, each of the included studies was of high quality, and a subgroup analysis was performed to reduce the heterogeneity when necessary. Overall, the pooled results of this study have a certain clinical guiding significance.

CONLUSION

The results showed that prior tantalum rod implantation of LIHP increased the difficulty of conversion to THA, which was reflected mainly in the longer operative time and greater intraoperative blood loss. Simultaneously, easier intraoperative fracture and stem malalignment in the LIHP group tend to be observed than in the control THA group. These factors should be considered during preoperative preparation. However, what our group supported is that these challenges and pitfalls will be overcome with the technological advances in THA. So, hip preservation surgery should be applied to young patients if this procedure has been shown to be effective and safe.

DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding author.

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CONFLICT OF INTEREST STATEMENT

None declared.

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