EPiC Series in Health Sciences
Volume 6, 2024, Pages 13–19
Proceedings of The 22nd Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

Robotic-assisted Total Hip Arthroplasty in Secondary Osteoarthritis of The Hip Joint Due to Developmental Hip Dysplasia: A Systematic Review And Meta-analysis

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Abstract

Robotic-assisted total hip arthroplasty (raTHA) was introduced in recent decades, offering proven advantages in improving the acetabular cup placement. However, the use of raTHA requires specific equipment and additional cost of $1,788 per case, raising the question of its cost-effectiveness. We believe that the use of raTHA may be substantially advantageous in complicated cases such as developmental dysplasia of the hip (DDH) with deformed anatomy, where proper prosthesis alignment is hard to achieve. Therefore, we conducted a systematic review and meta-analysis in accordance with the 2020 PRISMA to evaluate the benefits of raTHA over conventional total hip arthroplasty in DDH patients. From 80 studies that we found, only three were eligible. We primarily focused on the radiological outcomes and complications. However, functional outcomes were not compared and analyzed due to differences in reporting formats among the original studies. The analyses proved that raTHA was associated with a significantly increased rate of cup placement within Lewinnek's and Callanan's safe zone. All studies had no report of any complications and revisions during the short term follow-up. Although statistical precision may have been affected by a limited number of studies, our review offers the first and most recent evidence-based analysis of the use of raTHA in secondary osteoarthritis caused by DDH. This meta-analysis revealed the potential benefits of the raTHA in improving radiological outcomes, which may outweigh the total costs in such well-selected cases.

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1. Introduction

While total hip arthroplasty is considered one of the most successful orthopedic procedures, proper implant positioning is essential to improve longevity and avoid complications (Dimitriou et al., 2018). Achieving optimal prosthesis alignment is particularly challenging in cases with deformed anatomy, such as developmental dysplasia of the hip (DDH) (Yetkin et al., 2021).

Computer-assisted total hip arthroplasty has been developed to provide intraoperative real-time alignment information, allowing surgeons to assess and adjust implant placement. As a result, robotic-assisted total hip arthroplasty (raTHA) was introduced, incorporating further technological advancements, precise planning, and accurate bone cutting (Davenport et al., 2016; St Mart et al., 2020). Several studies have consistently reported that raTHA yields superior radiological outcomes with fewer intraoperative complications (Han et al., 2019; Emara et al., 2021). While many clinical trials have compared raTHA with manual total hip arthroplasty (mTHA), only few of them specifically focused on DDH patients. We aimed to systematically review the benefits of raTHA in these complex cases.

2. Methodology

This systematic review was conducted in accordance with the 2020 PRISMA guidelines (Page et al., 2021). We conducted a comprehensive search of electronic literature on PubMed, Embase, and Cochrane Library databases using the following search terms: (“Developmental dysplasia of the hip”, “hip dysplasia”) AND (“total hip arthroplasty”, “total hip replacement”) AND (“conventional”, “manual”, “Robotic Assisted Surgery” and “Robotic Surgical Procedure”) to compare raTHA and mTHA. Two independent researchers (G.C. and J.S.) conducted the search and reviewed the abstracts. Our inclusion criteria were all clinical trials comparing the use of raTHA and mTHA in DDH patients, while exclusion criteria included non-comparative studies and studies published in languages other than English. Out of 80 studies found, only 3 studies met our inclusion criteria after removing duplicates and irrelevant studies. The same two investigators performed data extraction and risk of bias assessment (using ROBINS-I) (Sterne et al., 2016). In cases of disagreement, a third reviewer (U.P.) was consulted for discussion.

The statistical analyses were conducted using mean and odds ratio with 95% confidence interval (95% CI). Heterogeneity of the study was expressed by I^2. The random effect model was used when the heterogeneity between the studies was significant ($I^2 > 50\%$). However, the fixed effect model was chosen when heterogeneity was not significant ($I^2 < 50\%$). All analyses were conducted using Review Manager 5.4.1.

3. Results

3.1. Study characteristics

Our final analysis included 3 studies, each comparing radiological outcomes and complications between raTHA and mTHA using the same semi-active robotic system, MAKO (Stryker Corporation, Kalamazoo, MI, USA) (St Mart et al., 2020). The studies involved a total of 170 hips in each intervention group. The mean age, gender, body mass index (BMI), severity, surgical approaches, and methodological quality were described in Table1.

Table 1: Demographic data of included studies

Author	Zhou Y. [9]		Chai W. [10]		Sato K. [11]	
Study Design	Retrospective		Retrospective (PSM)		Retrospective (PSM)	
Country	China		China		Japan	
Year	2021		2022		2022	
Robotic system	MAKO; Stryker		MAKO; Stryker		MAKO; Stryker	
Number of surgeons	3 surgeons		Multiple surgeons		9 surgeons	
Interventions	raTHA	mTHA	raTHA	mTHA	raTHA	mTHA
Hips	59	59	27	27	84	84
Severity (Crowe Classification)	I = 36 II, III = 13 IV = 10	I = 36 II, III = 13 IV = 10	III = 10 IV = 17	III = 6 IV = 21	I = 81 II = 3 III, IV = 0	I = 80 II = 4 III, IV = 0
Age	49.9 +- 11.2	49.7 +- 11.5	43.04 +- 8.92	44.56 +- 9.53	66 +- 8	66 +- 8
Gender (Female)	74.6%	74.6%	100%	100%	98.8%	98.8%
BMI	24.5 +- 3.3	24.7 +- 2.8	24.34 +- 4.6	22.8 +- 3.11	23.9 +- 3.4	24.0 +- 4.6
Surgical approaches	Posterolateral approach		Posterolateral approach		Modified Watson-Jones approach	
Outcomes	(1),(2),(3)		(1),(2),(3)		(3)	
Risk of Bias	Moderate		Low		Moderate	

PSM: Propensity score matching; (1) Cup placement within Lewinnek's and Callanan's safe zone; (2) Operative time; (3) Complications

3.2 Accuracy of cup placement within Lewinnek's and Callanan's safe zone

Percentage of the acetabular cup placement within Lewinnek's and Callanan's safe zone were mentioned in 2 studies (Zhou et al., 2021; Chai et al., 2022). The mean cup inclination angles were 42.32 +- 4.7 degrees in raTHA and 42.75 +- 6.0 degrees in mTHA, while mean cup anteversion angles were 15.17 +- 6.98 degrees and 19.67 +- 9.9 degrees, respectively. The analyses demonstrated that the use of raTHA significantly improved the accuracy of cup placement in Lewinnek's safe zone from 66.3% to 95.3% with odds ratio of 12.32 and 95% CI (1.40, 108.81; p = 0.02). Additionally, the raTHA was associated with the higher accuracy of cup placement in Callanan's safe zone from 46.5% to 86% with odds ratio of 11.09 and 95% CI (1.10, 111.64; p= 0.04).

3.3 Operative time

Our research included 3 studies reporting operative time(Zhou et al., 2021; Chai et al., 2022; Sato et al., 2022). The mean operative time of the raTHA group was 81.89 +- 35 minutes, which was longer than the mTHA group (71.22 +-38.1 min). The analysis revealed that the use of raTHA tended to extend the operative time with mean difference of 11.12 minutes with 95% CI (-3.45, 25.69; p = 0.13) but failed to reach statistical significance.

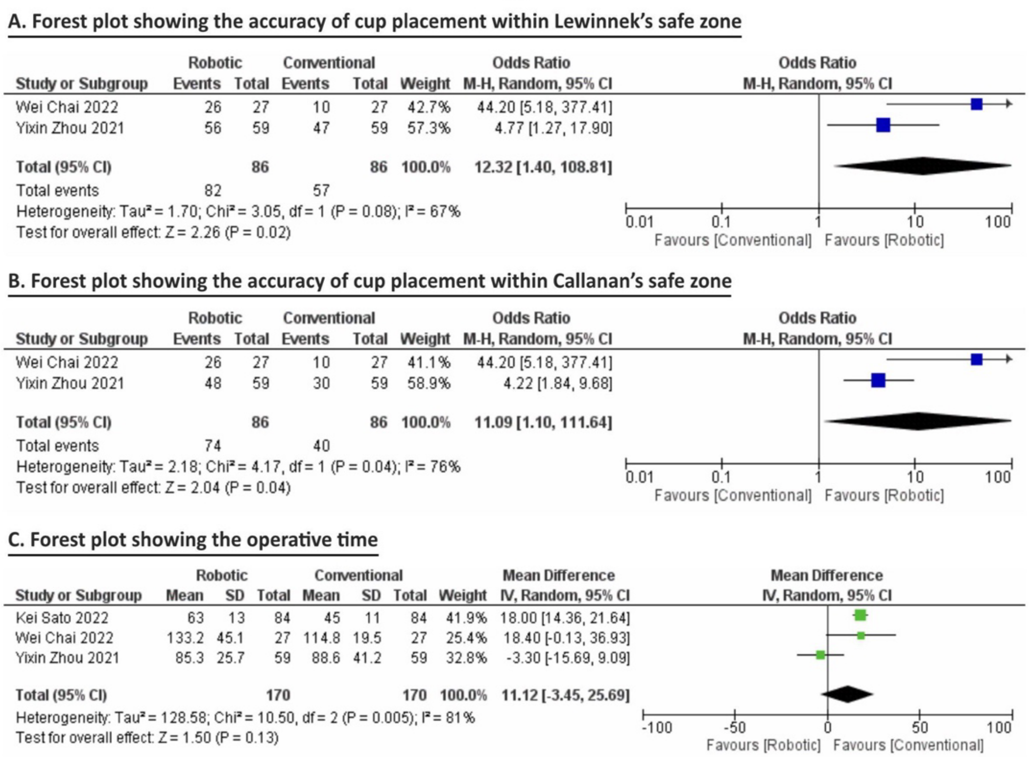

Figure 1: Forest plot showing the accuracy of cup placement within Lewinnek's safe zone (A), Forest plot showing the accuracy of cup placement within Callanan's safe zone (B), Forest plot showing the operative time (C)

3.4 Other complications

The follow-up period ranged from 3 months to 2 years, and there were no reported complications, such as fracture, dislocation, iatrogenic nerve injury, loosening, or revision, in either group.

4. Discussion

Achieving optimal implant position in secondary osteoarthritis of the hip joint due to DDH has been challenging for surgeons (Wang et al., 2019). Although the potential benefits of raTHA in improving implant placement within the safe zone have been proven in the general population, only a few studies have established the use of raTHA in DDH. In DDH patients, raTHA has been acknowledged for several advantages, including optimization of cup alignment, restoration of leg length, and offset according to the preoperative plans (Vigdorchik et al., 2020; Xu et al., 2021). Compared to general population, raTHA resulted in satisfying improvement of radiological and functional outcomes in both DDH and non-DDH groups without significant differences (Hayashi et al., 2021).

With regard to cup alignment, there was significantly better cup placement within Lewinnek's and Callanan’s safe zone in the raTHA group when compared to the mTHA group, corresponding to previous studies (Han et al., 2019; Emara et al., 2021). However, we were unable to analyze the functional outcomes since the outcome measurements in each study were reported in different formats. Nevertheless, none of the published meta-analyses represented significant differences in functional scores between the two groups (Kort et al., 2021).

In agreement with most studies, our analysis demonstrated the longer operative time in the raTHA group as a result of additional processes on registration and positioning verification. The heterogeneity among the studies could be influenced by many factors such as surgeons’ experiences. The higher mean volume of blood loss was found in the raTHA group. There were no significant differences in terms of complications or revisions during short-term follow-up.

Additionally, computer-navigated total hip arthroplasty (nTHA) is another potential tool for achieving optimal placement of the acetabular cup. One case-control study indicated that CT-based navigation systems could achieve precise placement of the acetabular component in patients with Crowe type IV hip dysplasia, with a similar level of accuracy as those with Crowe type I (Ueoka et al., 2019). However, according to another study from Ando W. et al., comparing the use of nTHA and raTHA, the robotic group associated with more precision and accuracy of final cup alignment (Ando et al., 2021).

Overall, it is still debatable whether this improvement of prosthesis alignment has a substantial impact on clinical outcomes. Economic issues have been concerned for the implementation of raTHA since the average additional inpatient hospital costs were $1,788 (Kirchner et al., 2021). Further studies with long-term follow-up are needed to draw a solid conclusion on the cost-effectiveness.

The limited number of the studies with considerably small sample size accounted for the lower precision of statistical results. The drawbacks of this meta-analysis included the inability to retrieve complete data from each study. Additionally, all included studies used the same robotic system, which may limit the generalizability of the findings. Despite these limitations, we have provided the first and most recent evidence-based review of the use of raTHA in secondary osteoarthritis due to DDH.

5. Conclusion

This meta-analysis demonstrates the potential benefits of raTHA in managing secondary osteoarthritis due to DDH, as it can significantly improve radiological outcomes. Although the procedure comes with higher costs, its use in well-selected cases may be justified.

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