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Opening-Wedge vs. Closing-Wedge High Tibial Osteotomy for Medial Compartmental Knee Osteoarthritis: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

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ABSTRACT

Introduction: The main purpose of HTO is to put off the start of sickness and the requirement for a knee replacement for as long as possible. The opening wedge high tibial osteotomy (OWHTO) and the closing wedge high tibial osteotomy (CWHTO) are the two surgical techniques that are performed the most frequently.

Objective: The aim of this meta-analysis of randomized controlled trials (RCTs) is to compare OWHTO with CWHTO with regard to clinical and radiological results as well as adverse events.

Materials and methods: PubMed, Embase, Web of Science, and Scopus were searched for RCTs comparing OWHTO and CWHTO for the outcomes of interest. We collected information on the rate of complications, as well as the clinical and radiological results. **Results:** There were a total of 648 participants across 11 trials that met our inclusion criteria; 324 patients received OWHTO and 326 individuals had CWHTO. Our study showed that OWHTO is linked to a more sloping tibia, a lower patellar height, a longer leg length, and a higher rate of metal removal. Overall effectiveness, degrees of angular rectification, and incidences of complications were comparable between the two methods. **Conclusion:** Although OWHTO and CWHTO demonstrated different effects on PTS, patellar height, and leg length, no technique was found to be superior in terms of functional outcomes, and postoperative complications. We need more RCTs with similar populations, big sample numbers, and extended follow-up periods.

Keywords: Opening-wedge, closing-wedge, tibial osteotomy, osteoarthritis, meta-analysis, Egypt.

INTRODUCTION

Progressive cartilage breakdown and physical deterioration characterize osteoarthritis (OA), the most prevalent condition of the knee joint **(1)**. When knee OA has progressed, the best surgical choice for therapy is a total knee arthroplasty (TKA) **(2)**. However, high tibial osteotomy (HTO) and other surgical treatments have shown promise in treating medial compartment OA in young, active individuals **(3)**. The major aim of HTO is to delay the advancement of the illness and avoid the need for knee replacement **(4)**.

Jackson and Waugh **(5)** initially described HTO in 1961. The most common procedures are (OWHTO) and (CWHTO). There are benefits and drawbacks to every approach. OWHTO's theoretical benefits include bone stock preservation, the lack of fibular osteotomy, and the avoidance of peroneal palsy **(3, 6)**. OWHTO is becoming increasingly popular as a result of the development of innovative bone-substituting biomaterials in conjunction with the introduction of new implants that have a firm locking mechanism. In earlier research, comparing the two approaches did not reveal a statistically significant difference in either the functional outcomes or the rates of complications **(7)**.

In order to find a solution to the problem, we carried out a meta-analysis of randomized controlled trials (RCTs), in which we compared the outcomes of OWHTO and CWHTO in terms of clinical and radiological findings, as well as adverse events.

MATERIALS AND METHODS

The Preferred Reporting Items for Systematic Reviews & Meta-Analyses (PRISMA) checklist was used to guide our systematic review. (Open) AND (Closed OR Closing) AND (Tibial Osteotomy) was used to search PubMed, Embase and Web of Science from their creation to June 2023. Endnote X9 (Thomson Reuters, New York, NY, USA) was utilizes for importing the retrieved results and perform a duplicate-content search.

After that, the titles and abstracts of the remaining publications were reviewed using the following criteria to determine which ones should be excluded: Content originally published in languages outside English, analyses, recommendations, and categorizations. Case reports, brief case series, and conference articles. Research using cultured cells and animals, studies that don't matter.

After identifying papers that could be relevant, we collected their full texts and evaluated them for inclusion.

Studies were included in our analysis if they fulfilled one of the following inclusion criteria: Comparing OWHTO to CWHTO for medial compartment knee OA in randomized controlled trials, a minimum of 6 months of follow-up, obtaining information necessary for making comparisons.

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Data extraction and quality assessment:

Two reviewers looked over the list of possible references and extracted the data, with a third reviewer weighing in on eligibility questions as appropriate. Studies that met the inclusion criteria were abstracted for the following information: first author, year published, country, number of participants in each group, participants' age, gender, and body mass index, side of procedure, method of fixation, length of follow-up, and outcomes of interest (such as functional knee scores like the KSS, HSS, Western Ontario, and McMaster University Knee Scores), radiographic markers such hip-knee-ankle (HKA) angle, patellar height, posterior tibial slope (PTS), leg length change (LLC), and postoperative problems. We assessed RCTs bias using the Cochrane Collaboration's quality assessment technique [8]. Two reviewers independently assessed the paper, and the main author resolved conflicts.

Ethical Approval:

The study was approved by the Ethics Board of Burjeel Hospital. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical analysis

Review Manager 5.4.1 was used for all statistical analyses. released in 2014 by the Copenhagen-based Nordic Cochrane Centre of The Cochrane Collaboration. We calculated discrete outcome odds ratios and 95% confidence intervals (CIs). We calculated mean difference and 95% CI for continuous variables. We calculated the overall effect estimate with 95% CI using a fixed-effect model with Mantel-Haenszel when trials were homogeneous. Otherwise, we used a DerSimonian and Laird random-effects model. Q and I2 tests measured effect estimate heterogeneity across studies. P<0.05 determined significance.

RESULTS

A total of 717 references were found through the computerized search of the four databases. Only 451 entries met the criteria for title/abstract screening after removing 266 duplicates. Thirty papers met the criteria for a full-text review, but only eleven were accepted. No new articles were imported after a manual search of references. In all, 11 papers [9-19] met the criteria for inclusion in the quantitative and qualitative reviews. The process diagram appears in **Figure 1**.

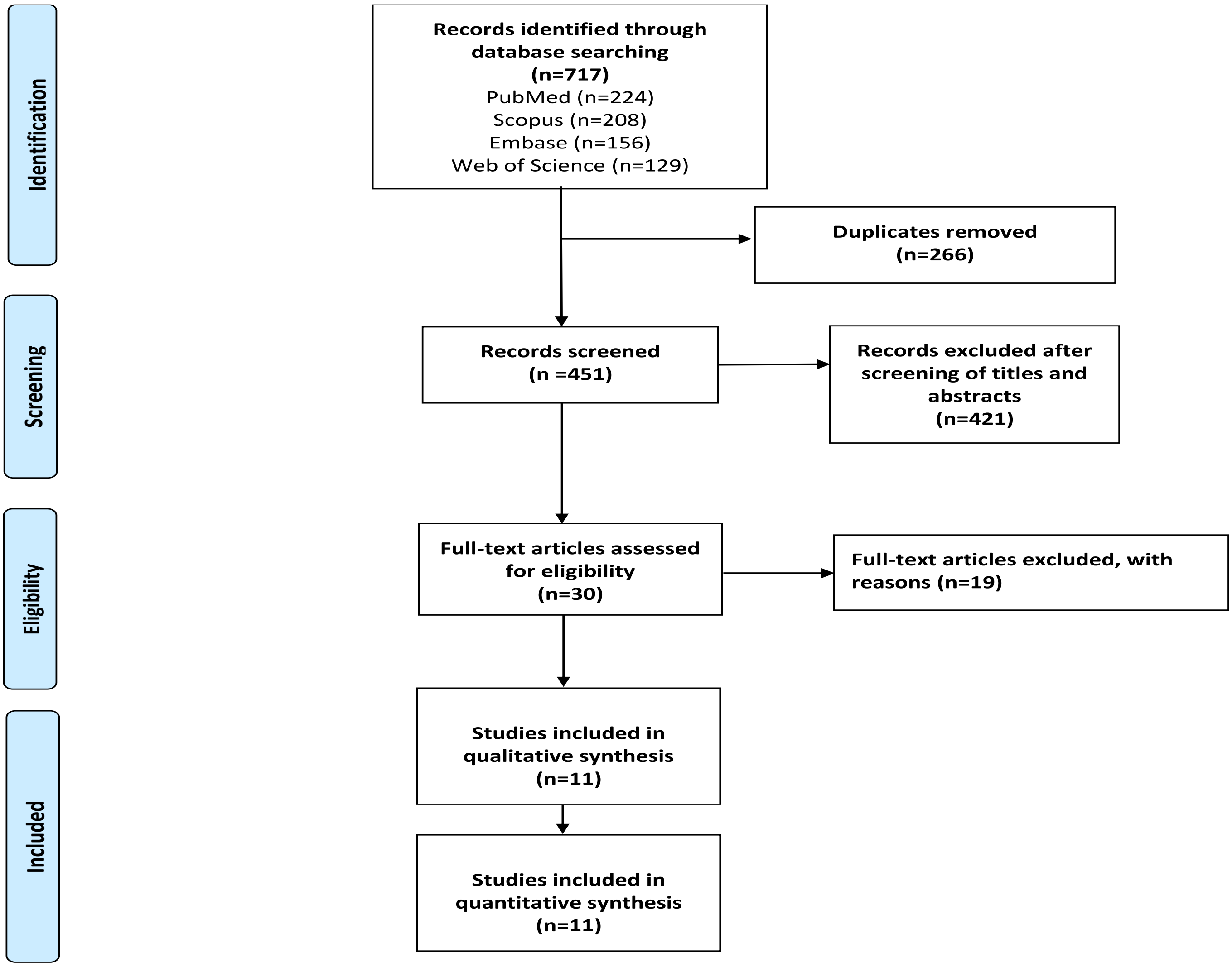

Figure 1: Flow Diagram of Study Selection Process.

Risk of Bias within Studies

Figures 2 and **3** illustrate the risk of bias that was present in the studies that were included. This risk of bias was related to the production of random sequences, the concealment of allocations, the blinding of participants and workers, the blinding of outcome assessment, inadequate outcome data, selective reporting, and other types of bias. The risk is either very low or cannot be determined across all of the studies that were considered.

Table 1 summarizes study details that were considered for inclusion. There were a total of 648 participants from 11 trials included in the meta-analysis; 324 patients received OWHTO and 326 patients underwent CWHTO. All of the papers that were considered were randomized clinical trials. The average age of participants in OWHTO trials was 47–55, while in CWHTO studies it was 49.4 to 54.1 years old. Between 6 months and 7.9 years, patients were followed.

Table 1: summarisation of details that were considered for inclusion in the study.

First Author	Country	Sample Size	Fixation	Age (years)	BMI (kg/m^2)	Female (%)	Right Knee (%)	Follow-up (years)
Magyar, [16]	Sweden	25/25	EF/Staples	55/50	NA	NA	NA	2
Magyar ***et al.*** [17]	Sweden	19/16	EF/Staples	55/53	29/28	42/19	NA	1
Brouwer, [11]	Netherlands	26/24	Puddu/Staples	48/52	NA	23/50	NA	1
Brouwer, [12]	Netherlands	45/47	Puddu/Staples	50/51	28/28	29/43	56/53	1
Luites, [15]	Netherlands	23/19	TomoFix	53	NA	36	NA	2
Gaasbeek ***et al.*** [9]	Netherlands	25/25	Four-hole locked plate	47/50	30/28	44/36	NA	1
Duivenvoorden, [13]	Netherlands	36/45	Puddu/Staples	50/50	27/28	33/40	NA	6
Egmond, [14]	Netherlands	25/25	Four-hole locked plate	47/50	30/28	40/36	36/68	7.9
Nerhus, [10]	Norway	35/35	Puddu/Staples	NA	NA	NA	NA	0.5
Kim, [19]	South Korea	30/30	TomoFix/Stepped Plate	54/54	24/26	70/67	53/57	1
Nerhus, [18]	Norway	35/35	Puddu/Staples	51/49	NA	43/51	54/49	2

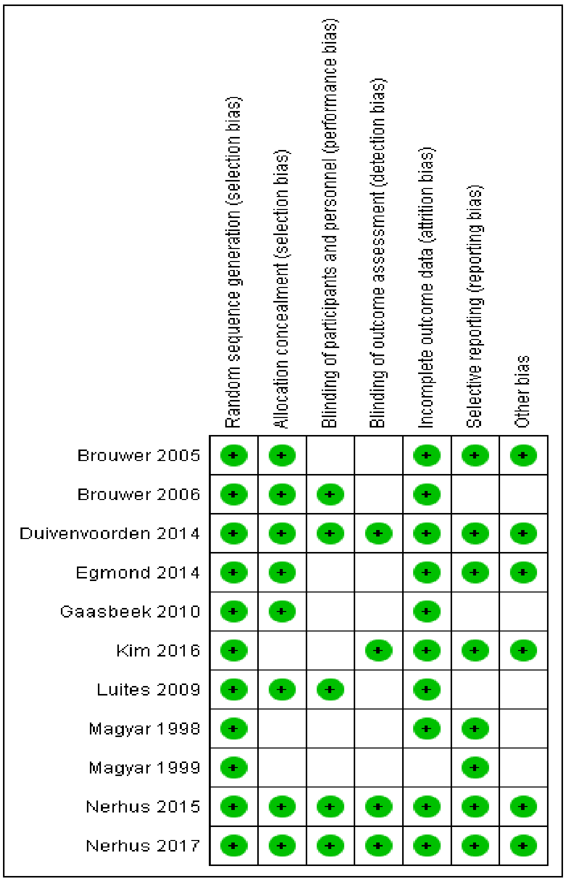

Figure 2: Graph Showing the Potential for Bias in the Included RCTs

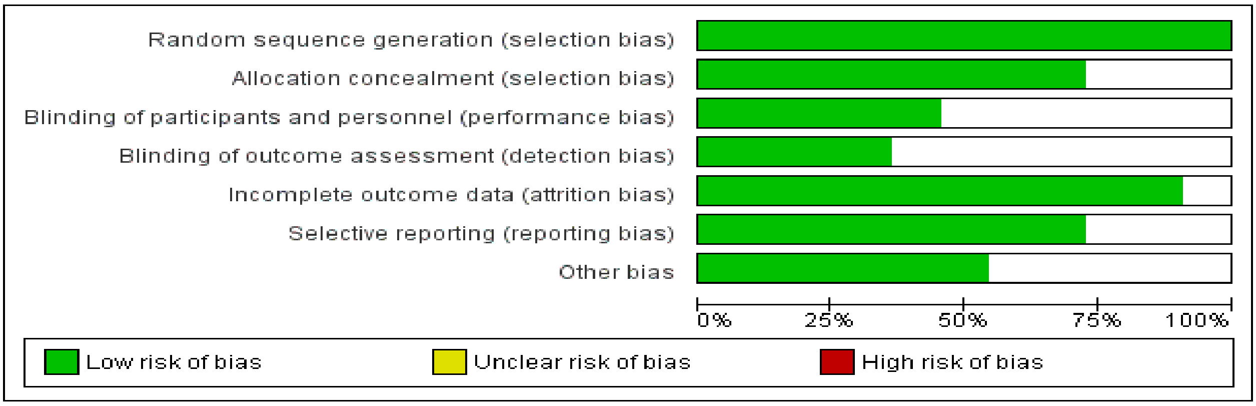

Figure 3: Risk of Bias Summary of Included RCTs.

Meta-Analysis of Clinical Outcomes (Figures 4-9)

In all, eight studies reported differences in postoperative functional outcomes, including VAS for pain, HSS, Lysholm score, WOMAC, Tegner activity score & walking distance. Using the fixed effects model, we were unable to identify any differences that were statistically significant. There was no statistically significant difference between OWHTO and CWHTO in terms of pain VAS, health status score, Lysholm score, Western Ontario and McMaster University Disability Index (WOMAC), Tegner activity score, or walking distance.

	OWHTO			CWHTO				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**
Magyar 1998	0	1.5	25	0	0.8	25	25.1%	0.00 [-0.67, 0.67]
Brouwer 2006	3.6	2.9	45	3.6	2.2	47	10.0%	0.00 [-1.06, 1.06]
Luites 2009	1.5	2.5	23	2.3	3.2	19	3.6%	-0.80 [-2.56, 0.96]
Gaasbeek 2010	2.5	1.9	25	1.8	1.5	25	12.4%	0.70 [-0.25, 1.65]
Duivenvoorden 2014	3.4	3.2	36	4	3.2	45	5.7%	-0.60 [-2.00, 0.80]
Egmond 2014	4.1	2.6	19	2.8	2.7	19	3.9%	1.30 [-0.39, 2.99]
Kim 2016	1.5	0.5	30	1.1	1.4	30	39.4%	0.40 [-0.13, 0.93]
Total (95% CI)			**203**			**210**	**100.0%**	**0.23 [-0.10, 0.57]**

Heterogeneity: Chi² = 6.18, df = 6 (P = 0.40); I² = 3%
Test for overall effect: Z = 1.37 (P = 0.17)

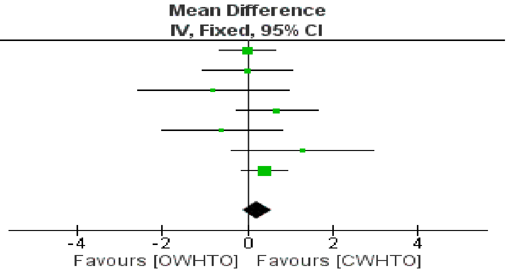

Figure 4: There is not a statistically significant difference among OWHTO & CWHTO, as demonstrated by the forest plot of VAS.

	OWHTO			CWHTO				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**
Magyar 1998	94	7.8	25	89	10.3	25	7.6%	5.00 [-0.06, 10.06]
Brouwer 2006	80.9	13.5	45	79.4	12	47	7.2%	1.50 [-3.73, 6.73]
Duivenvoorden 2014	80.8	13.8	36	81.1	13	45	5.6%	-0.30 [-6.19, 5.59]
Kim 2016	92.2	3.1	30	93.7	3.1	30	79.6%	-1.50 [-3.07, 0.07]
Total (95% CI)			**136**			**147**	**100.0%**	**-0.72 [-2.12, 0.68]**

Heterogeneity: Chi² = 6.56, df = 3 (P = 0.09); I² = 54%
Test for overall effect: Z = 1.01 (P = 0.31)

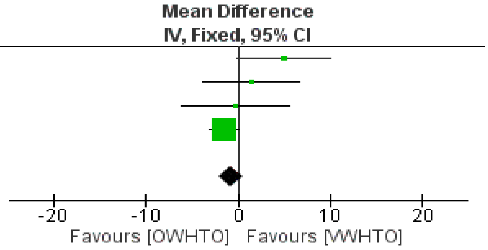

Figure 5: There is not a statistically significant difference among OWHTO & CWHTO when compared using the forest plot of HSS.

	OWHTO			CWHTO				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**
Magyar 1998	91	11.3	25	86	14.3	25	41.1%	5.00 [-2.14, 12.14]
Luites 2009	86	13	23	80	18	19	22.4%	6.00 [-3.68, 15.68]
Nerhus 2017	70.6	15.7	35	73.8	16.6	35	36.6%	-3.20 [-10.77, 4.37]
Total (95% CI)			**83**			**79**	**100.0%**	**2.22 [-2.35, 6.80]**

Heterogeneity: Chi² = 3.14, df = 2 (P = 0.21); I² = 36%
Test for overall effect: Z = 0.95 (P = 0.34)

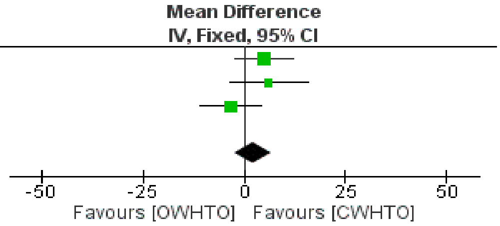

Figure 6: It can be seen from the forest plot of the Lysholm score that there is no statistically significant difference among OWHTO & CWHTO.

	OWHTO			CWHTO				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**
Gaasbeek 2010	20	19.4	25	16	15	25	72.7%	4.00 [-5.61, 13.61]
Egmond 2014	36.2	26.8	19	21.1	22.3	19	27.3%	15.10 [-0.58, 30.78]
Total (95% CI)			**44**			**44**	**100.0%**	**7.03 [-1.16, 15.23]**

Heterogeneity: Chi² = 1.40, df = 1 (P = 0.24); I² = 29%
Test for overall effect: Z = 1.68 (P = 0.09)

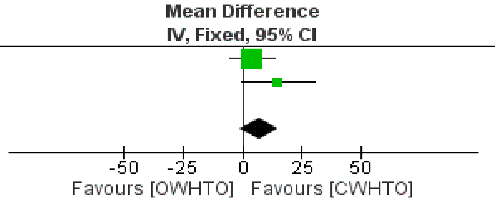

Figure 7: The WOMAC score forest plot reveals that there is no statistically significant difference among OWHTO & CWHTO.

Study or Subgroup	OWHTO Mean	OWHTO SD	OWHTO Total	CWHTO Mean	CWHTO SD	CWHTO Total	Weight	Mean Difference IV, Fixed, 95% CI
Magyar 1998	10	2	25	9	2	25	27.5%	1.00 [-0.11, 2.11]
Nerhus 2017	2.9	1.3	35	3.1	1.6	35	72.5%	-0.20 [-0.88, 0.48]
Total (95% CI)			**60**			**60**	**100.0%**	**0.13 [-0.45, 0.71]**

Heterogeneity: Chi² = 3.26, df = 1 (P = 0.07); I² = 69%
Test for overall effect: Z = 0.44 (P = 0.66)

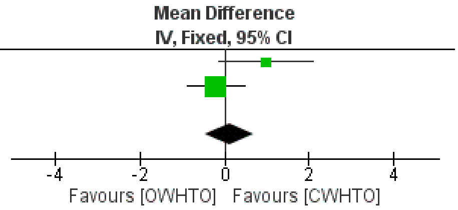

Figure 8: There is not a statistically significant difference among OWHTO & CWHTO, as seen by the forest plot of the Tegner activity score.

Study or Subgroup	OWHTO Mean	OWHTO SD	OWHTO Total	CWHTO Mean	CWHTO SD	CWHTO Total	Weight	Mean Difference IV, Fixed, 95% CI
Brouwer 2006	5.3	4.4	45	4.6	3.6	47	58.8%	0.70 [-0.95, 2.35]
Duivenvoorden 2014	8.2	4.7	36	6.7	4.2	45	41.2%	1.50 [-0.47, 3.47]
Total (95% CI)			**81**			**92**	**100.0%**	**1.03 [-0.23, 2.29]**

Heterogeneity: Chi² = 0.37, df = 1 (P = 0.54); I² = 0%
Test for overall effect: Z = 1.60 (P = 0.11)

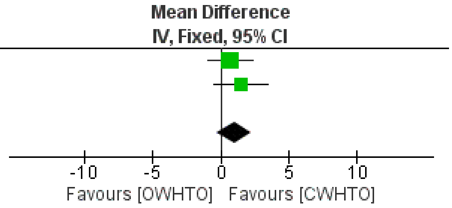

Figure 9: There is not a statistically significant difference among OWHTO & CWHTO when it comes to the forest plot of walking distance.

Meta-analysis of Radiological Outcomes

HKA Angle (Figure 10): Nine various studies found significant differences in the HKA angle. Because there was clear evidence of high heterogeneity (I2=69%, P=0.001), we conducted our analysis using a random effects model. The overall MD and 95% CI came out to be -0.59 (ranging from -1.78 to 0.59) (P=0.33). This reveals that there is no statistically significant difference among OWHTO and CWHTO concerning the change in HKA.

Study or Subgroup	OWHTO Mean	OWHTO SD	OWHTO Total	CWHTO Mean	CWHTO SD	CWHTO Total	Weight	Mean Difference IV, Random, 95% CI
Magyar 1998	9	4.3	25	11	5.4	25	9.0%	-2.00 [-4.71, 0.71]
Magyar 1999	12	3.7	19	12	5.4	16	7.8%	0.00 [-3.13, 3.13]
Luites 2009	7	5.6	45	10.2	4.7	47	11.0%	-3.20 [-5.32, -1.08]
Brouwer 2006	3.4	3	23	0.9	2	19	13.3%	2.50 [0.98, 4.02]
Gaasbeek 2010	8.1	3.3	25	8.5	3.4	25	12.0%	-0.40 [-2.26, 1.46]
Duivenvoorden 2014	6.3	6.4	36	9.2	6.1	45	8.9%	-2.90 [-5.65, -0.15]
Egmond 2014	7.3	2.3	18	7.6	3.2	18	12.1%	-0.30 [-2.12, 1.52]
Nerhus 2015	6.4	3.5	35	6.8	4.4	35	12.0%	-0.40 [-2.26, 1.46]
Kim 2016	12.2	1.7	30	12.2	3.4	30	13.9%	0.00 [-1.36, 1.36]
Total (95% CI)			**256**			**260**	**100.0%**	**-0.59 [-1.78, 0.59]**

Heterogeneity: Tau² = 2.15; Chi² = 25.41, df = 8 (P = 0.001); I² = 69%
Test for overall effect: Z = 0.98 (P = 0.33)

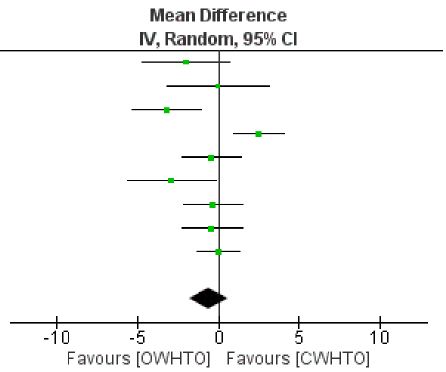

Figure 10: There is not a statistically significant difference in the HKA change among OWHTO and CWHTO, as demonstrated by the forest plot.

Patellar Height (**Figure 11**).

Four studies reported differences in patellar height change. No significant heterogeneity was detected, using the fixed effects model for analysis (I^2=0%, P=0.52). The combined MD and 95% CI was -0.09 (-0.16 to -0.03). This reveals a statistically significant difference between OWHTO and CWHTO regarding change in patellar height (P=0.005).

Study or Subgroup	OWHTO Mean	OWHTO SD	OWHTO Total	CWHTO Mean	CWHTO SD	CWHTO Total	Weight	Mean Difference IV, Fixed, 95% CI
Brouwer 2005	-0.09	0.3	26	0.01	0.2	24	21.1%	-0.10 [-0.24, 0.04]
Gaasbeek 2010	-0.14	0.2	25	0.04	0.3	25	20.8%	-0.18 [-0.32, -0.04]
Egmond 2014	-0.1	0.3	18	0	0.3	18	10.8%	-0.10 [-0.30, 0.10]
Nerhus 2015	-0.03	0.2	35	0.02	0.2	35	47.3%	-0.05 [-0.14, 0.04]
Total (95% CI)			**104**			**102**	**100.0%**	**-0.09 [-0.16, -0.03]**

Heterogeneity: Chi² = 2.28, df = 3 (P = 0.52); I² = 0%
Test for overall effect: Z = 2.83 (P = 0.005)

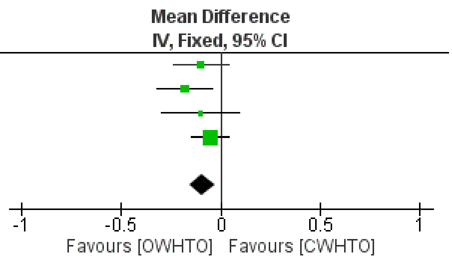

Figure 11: A statistically significant difference may be shown among OWHTO and CWHTO when comparing the patellar height change illustrated by a forest plot.

Posterior Tibial Slope (**Figure 12**): Differences in PTS change were found in four different trials. Since there was clear evidence of considerable heterogeneity (I2=64%, P=0.04), we conducted the analysis with the random effects model.

3.15 was the combined MD and 95% CI, while the range for the MD was 1.40 to 4.91. This reveals that OWHTO and CWHTO have statistically significant differences with relation to the change in PTS (P<0.001).

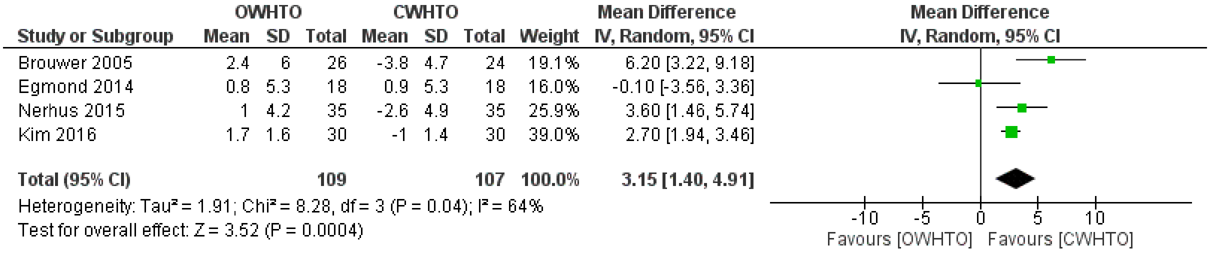

Figure 12: It can be seen from the forest plot of the PTS change that there is a statistically significant difference among OWHTO and CWHTO.

Leglength (**Figure 12**). Two studies found leg length variations. The fixed effects model showed no heterogeneity (I^2=0%, P=0.56). 8.70 (8.12–9.28) was the MD and 95% CI. OWHTO and CWHTO vary in leg length change (P<0.001).

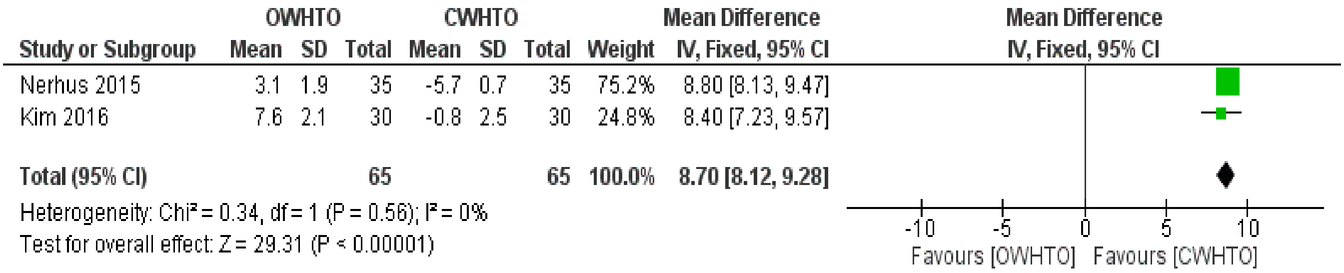

Figure 13: There is a statistically significant difference among both groups according to the forest plot that compares the leg length of OWHTO subjects with CWHTO subjects.

Postoperative Complications

We focused on nine side effects (Table 2) that were seen in at least two trials. These issues included metal removal, reoperation, conversion to arthroplasty, and infection at the surgical site (SSI), non-union, lateral hinge fracture (LHF), peroneal neuropathy, thromboembolic events, and non-union. Table 2 provides a summary of the findings from all of these issues taken together. Except for SSI, we did not find any substantial heterogeneity among analyses of complications; hence, we completed the meta-analysis using a fixed-effect model. The incidence of metal removal was the only postoperative complication that was significantly different among OWHTO and CWHTO.

Table 2. Meta-analysis of Postoperative Complications (N = 648).

Complication	No. Studies	OWHTO		CWHTO		Heterogeneity		Analysis Model	OR (95%CI)	P value
		Events	Total	Events	Total	I^2	P value			
SSI	6	26	194	6	198	62	0.02	Random	2.9 (0.5-17.3)	0.23
Non-union	4	4	148	6	148	63	0.07	Fixed	0.9 (0.3-2.6)	0.81
LHF	4	6	143	10	143	58	0.07	Fixed	0.6 (0.2-1.5)	0.24
Peroneal Neuropathy	5	2	180	6	184	0	0.95	Fixed	0.5 (0.2-1.7)	0.26
DVT	2	2	60	5	60	0	0.84	Fixed	0.4 (0.1-2)	0.28
Metal Removal	5	76	169	45	173	0	0.60	Foxed	2.7 (1.6-4.4)	0.001
Reoperation	5	9	169	14	173	37	0.17	Fixed	0.7 (0.3-1.5)	0.31
Conversion to Arthroplasty	4	7	144	15	148	0	0.48	Fixed	0.5 (0.2-1.2)	0.10

DISCUSSION

Realignment procedures such as valgus-producing HTO aim to unload the unhealthy medial compartment and shift the center of weight-bearing towards the relatively healthy lateral compartment in order to prevent or delay eventual knee arthroplasty [20]. OWHTO & CWHTO are the most commonly used HTO techniques. However, there is no consensus which technique is better.

Clinical and radiological results, as well as postoperative complications, were compared among OWHTO and CWHTO in this systematic review and meta-analysis of RCTs. The main findings of our study were that OWHTO and CWHTO had comparable functional outcomes, correction of varus deformity, and complication rates. However, both techniques demonstrated significant differences in terms of patellar height, PTS, and LLC postoperatively.

In the preset study, we found that OWHTO and CWHTO had similar postoperative pain levels measured by VAS for pain. Similarly **Smith *et al*.** [7] did not demonstrate a significant difference among OWHTO and CWHTO in terms of VAS for knee pain. Both techniques also achieved similar knee function as evaluated by HSS, Lysholm score, WOMAC, and Tegner activity score. Regarding postoperative walking distance, a mean difference of 1.03 (95% CI (-0.23; 2.29)) was calculated between OWHTO and CWHTO indicating no statistically significant difference among the 2 surgical techniques. Conversely, a previous study by **Wu *et al*.** [21] showed that OWHTO was linked with wider range of knee motion postoperatively which may be attributed to the differences in the rehabilitation protocols following each osteotomy technique.

Our radiological results were consistent with previous studies [7,21,22]**.** The degree of angular rectification, as assessed by shift in HKA angle, did not differ significantly across the groups. However, statistically significant differences were found between both techniques in terms of the changes in PTS, patellar height, and leg length. Unlike CWHTO, OWHTO has been found by previous studies to increase PTS mostly due to the anteromedial placement of the fixation device and inadequate release of posterior soft tissue structures [23]. Patients with cruciate ligament tears may benefit from PTS adjustments. Patients with torn anterior cruciate ligaments (ACLs) benefit from less slope, whereas those with torn posterior cruciate ligaments (PCLs) may benefit from more [24]. Our analysis showed that OWHTO and CWHTO had a statistically different impact on patellar height. In the OWHTO, a statistically significant reduction in patellar height was found. According to previous authors [25], The distalization of the tibial tubercle and/or the elevation of the tibiofemoral joint line likely contribute to the shortened patella. Therefore, OWHTO should be avoided in patients with preoperative patella baja or patellofemoral osteoarthritis. Furthermore, we found that OWHTO results in limb lengthening, while CWHTO results in limb shortening. A statistically significant difference was detected among groups concerning LCC. Our results were consistent with previous mathematical models predicting lengthening and shortening after OWHTO and CWHTO, respectively [26].

Regarding postoperative complications, our pooled results were comparable to previous studies [7,21,22]. We demonstrated no statistically significant difference among both groups in terms of SSI, non-union, LHF, peroneal neuropathy, thromboembolic events, reoperation, and conversion to arthroplasty. However, OWHTO group was related to a significantly higher metal removal rate matched to CWHTO.

LIMITATIONS

The main strength point of this meta-analysis was that it only included RCTs with either OWHTO or CWHTO. However, the study has a number of limitations, including small number of included articles, small sample size of most included studies, heterogeneity of fixation devices, and short follow-up durations.

CONCLUSION

Although OWHTO and CWHTO demonstrated different effects on PTS, patellar height, and leg length, no technique was found to be superior in terms of functional outcomes, and postoperative complications. More homogenous, high-quality RCTs with larger sample sizes and longer follow-up durations are recommended.

DECLARATIONS

- **Consent for publication:** I attest that all authors have agreed to submit the work.
- **Availability of data and material:** Available
- **Competing interests:** None
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