Systematic Review

Medial Opening Wedge (MOW) Versus Lateral Closing Wedge (LCW) High Tibial Osteotomies for Knee Medial Compartment Osteoarthritis Show Similar Outcomes and Survivorship, While MOW Has Higher Rates of Tibial Fracture and LCW Has Higher Rates of Nerve Injury and Conversion to Total Knee

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Purpose: To compare the clinical and radiographic outcomes and complications between medial opening wedge (MOW) and lateral closing wedge (LCW) high tibial osteotomies (HTOs) in the setting of medial compartment osteoarthritis with genu varus alignment. **Methods:** This study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Studies that reported on MOW or LCW HTOs in the setting of medial compartment osteoarthritis were included. Analysis was performed based on radiographic and patient-reported outcomes (PROs) and complications. **Results:** A total of 40 studies were included. Hip-knee-ankle angles and PROs, including Lysholm and visual analog scale, showed significant improvements postoperatively for both MOW and LCW HTO for all included studies. For the studies that reported on it, posterior tibial slope (PTS) was significantly increased in 4 of the 9 MOW studies and significantly decreased in 8 of the 9 LCW studies. Patellar height was significantly decreased in 4 of the 5 MOW studies, while none of the 4 LCW studies reported any changes. Three comparison studies reported a higher conversion to total knee arthroplasty in the LCW cohort; otherwise, survivorship at 10 years was comparable between studies. The MOW cohort had higher rates of tibial fractures, while the LCW cohort had higher rates of nerve injuries. **Conclusions:** This systematic review found comparable hip-knee-ankle angle correction and PROs between patients undergoing MOW or LCW HTOs to treat medial compartment osteoarthritis. Survivorship at 10 years was comparable between MOW and LCW HTOs; however, some MOW and LCW HTO comparison studies reported higher conversion to total knee arthroplasty for LCW HTO. Medial opening wedge HTO typically results in an increased PTS, decreased patellar height, and tibial fractures, while LCW HTO typically results in decreased PTS, no change in patellar height, and common peroneal nerve injuries. **Level of Evidence:** Level IV, systematic review of Level I to IV studies.

Osteoarthritis (OA) of the knee, specifically the medial compartment, is one of the most common joint disorders of the knee, especially affecting older adults.[1,2] Medial compartment OA is typically caused by a variety of factors, including trauma, meniscal deficiency, or osteochondral defects, which can be exacerbated by or can lead to varus mechanical alignment and degradation of the medial compartment cartilage.[3,4]

For the treatment of medial compartment OA, especially for younger patients or those looking to return to work or activities, a total knee arthroplasty (TKA) or unicompartmental medial arthroplasty (UKA) is not an optimal option.[5-7] High (proximal) tibial osteotomies (HTOs) to correct bony malalignment can allow patients to return to a generally active lifestyle and are the primary nonarthroplasty surgical options for the young arthritic knee.[6,8] An HTO is reported to be a joint-preserving technique that does not preclude a later TKA, and it preserves the native knee joint, can hinder the progression of osteoarthritis, and can delay the need

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for a TKA/UKA.[9-11] In cases of uncertainty as to whether an HTO is the best course of treatment, a trial using a medial unloader brace can help screen patients prior to undergoing an HTO.[12,13]

An HTO to correct varus alignment can be performed with either a medial opening wedge (MOW) or lateral closing wedge (LCW) osteotomy.[14,15] Each technique has its own advantages and disadvantages. Both have reported improved patient outcomes in the literature, but there is limited consensus as to which technique is better.[16,17] The purpose of this systematic review was to compare the clinical and radiographic outcomes and complications between MOW and LCW high tibial osteotomies in the setting of medial compartment osteoarthritis with genu varus alignment. We hypothesized that outcomes and complications of MOW and LCW would be similar.

Methods

Article Identification and Selection

This study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines and registered on PROSPERO International prospective register of systematic reviews (CRD42024579457). Searches were performed on PubMed, Embase, and Cochrane databases. Article identification was performed in August 2024. The following search terms were used: lateral closing wedge high tibial osteotomy (proximal tibial osteotomy), medial opening wedge high tibial osteotomy (proximal tibial osteotomy), medial compartment arthritis, and varus alignment. The search strategy utilized was as follows:

- (((opening wedge) OR (closing wedge)) AND ((high tibial osteotomy) OR (proximal tibial osteotomy)) AND ((outcomes) OR (complications)))

All studies from each database were uploaded to EndNote Reference Manager for duplicate article deletion. Two independent investigators (L.V.T., T.K.) reviewed all abstracts for inclusion criteria. Studies published before 2010 were excluded. Two reviewers (L.V.T., D.L.) examined all full texts of abstracts meeting the inclusion criteria. Furthermore, all systematic reviews found in the database were examined for additional relevant studies that may have been missed.

Data Collection

Patient demographics, radiographic outcomes, patient-reported outcomes (PROs), and complications were documented, and the most common overall results were reported. The radiographic outcomes chosen for analysis were the hip-knee-ankle (HKA) angle, posterior tibial slope (PTS), medial proximal tibial angle (MPTA), anatomic tibiofemoral angle (aTFA), and patellar height measured by either the Caton-Deschamps (CD) index, the Insall-Salvati index, or the Blackburne-Peel (BP) index. The PROs chosen for analysis were the Lysholm score, the visual analog scale (VAS) score, the Hospital for Specialty Surgery (HSS) score, and the Tegner score. The complications that were analyzed were conversion to TKA/UKA, delayed or nonunion, hardware removal, hinge fractures, tibial plateau fractures, and nerve injuries. Survivorship at 10 years was also assessed.

Data Analysis

Following data extraction, Excel (Microsoft) was utilized to compile the data. This systematic review compared the ranges of means from studies and avoided pooling the data due to the significant amount of heterogeneity between the studies and their reported data. Furthermore, no statistical subgroup analysis between MOW HTO and LCW HTO was possible. Comparisons between the groups were made based on observation and trends in the data.

Forest plots highlighting specific findings from the studies are reported in the results sections. These forest plots did not pool data and no comparison between MOW HTO and LCW HTO was performed due to the heterogeneity of the data. The data were reported as the mean differences between the pre- and postoperative values from the studies, and the 95% confidence intervals were calculated based on the standard deviation or the range divided by 4 when no standard deviation was reported.

When possible, the minimal clinically important difference (MCID) and patient acceptable symptomatic state were used to help classify the findings from the PROs.

Risk of Bias Assessment

The Methodological Index for Non-Randomized Studies (MINORS) was used to assess the included nonrandomized comparative or noncomparative studies for risk of bias.[18] This index uses 8 questions for noncomparative studies and 12 questions for comparative studies. Each category is assigned a score from 0 to 2. For noncomparative studies, a score <8 was considered poor quality, 9 to 13 was considered moderate quality, and 14 to 16 was considered high quality. For comparative studies, a score <14 was considered poor quality, 15 to 21 was considered moderate quality, and 22 to 24 was considered high quality. The Jahad scale was utilized for the risk of bias assessment for randomized comparative studies. The Jahad scale is out of 5 points and asks 3 questions related to randomization, blinding of the study, and dropouts. A score of 1 is considered a low-quality study, a score of 2 or 3 is considered a moderate-quality study, and a score of 4 or 5 is considered a high-quality study.

Results

Study Selection

The study selection process is represented in Figure 1. An initial article search using the search criteria listed in the Methods revealed 988 articles, and after duplicates were removed, 765 articles were assessed by title and abstract for inclusion. Of these, 54 articles were sought for full text retrieval, and 2 of these full texts could not be obtained. Of the final 52 articles, 7 had incomplete results, 2 reported on medial meniscus root tears, 1 reported on bilateral surgery, and 1 was a technique paper. This resulted in 41 articles being analyzed in this systematic review[6,19-57]; however, Amzallag et al.[21] and Ducat et al.[28] reported on the same patient cohort with different results and were thus combined in analysis. From the demographics section and beyond, only Amzallag et al.[21] will be cited for simplicity. With Amzallag et al.[21] and Ducat et al.[28] combined, 40 studies were analyzed. Fourteen studies reported on both MOW and LCW osteotomies,[19,21,27,29,30,37-39,42,43,46,49,53,54] 21 studies reported on just MOW osteotomies,[6,22,24,26,32-36,40,41,44,45,47,48,51,52,55-58] and 5 studies reported on just LCW osteotomies.[20,23,25,31,50] All studies reported medial compartment osteoarthritis and/or varus alignment as the indications for surgery.

Risk of Bias

Twenty-eight studies were nonrandomized, noncomparative studies and scored an average of 10.4/16

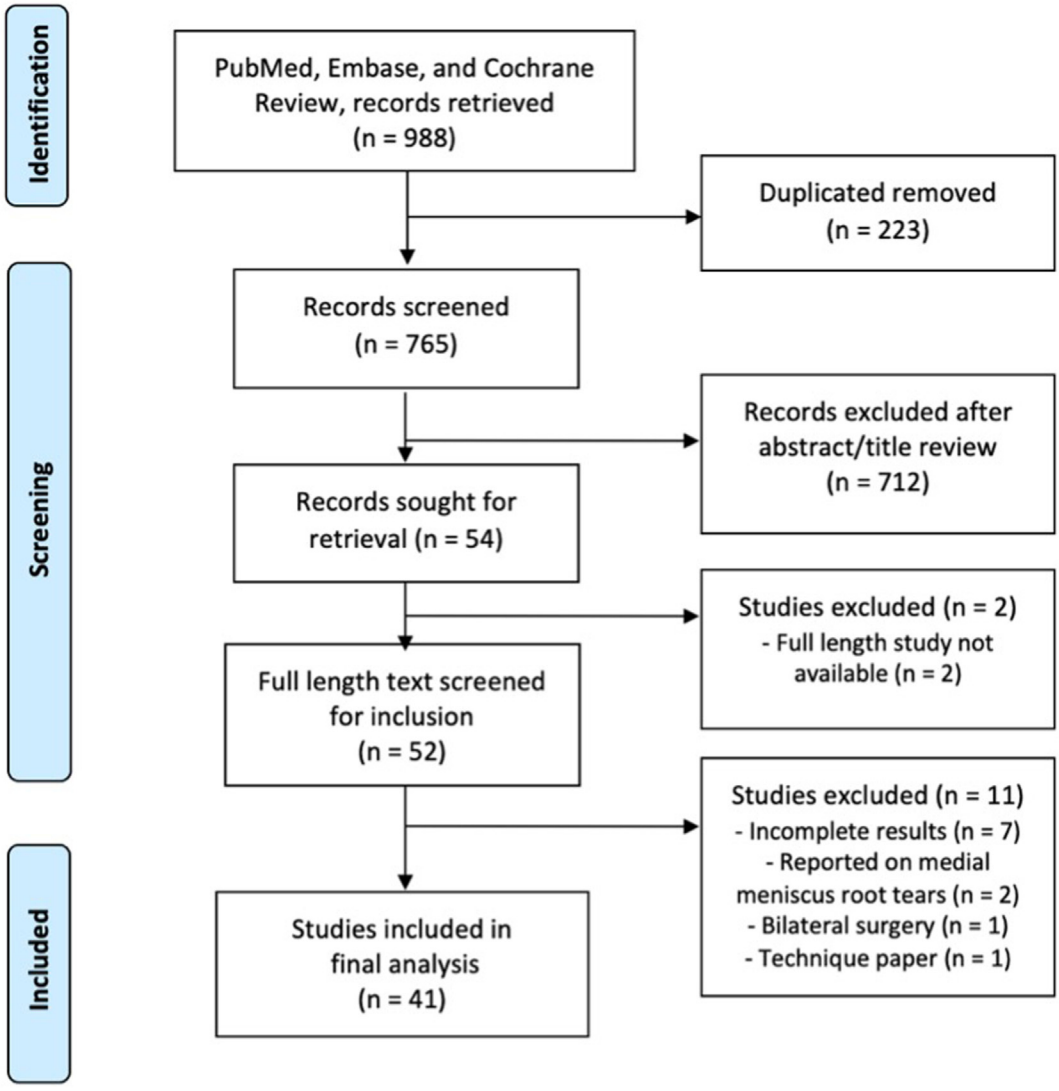

Fig 1. Study selection was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. A total of 765 studies were screened based on the initial search criteria. After abstract and title review, 54 were assessed for inclusion. After 2 full-length studies could not be found, another 11 studies were excluded: 7 studies had incomplete results, 2 studies only reported on medial meniscus root tears, 1 study reported on bilateral surgery, and 1 study was a technique paper. Forty-one studies were ultimately included for analysis.

(range, 8-14) on the MINORS scale (Appendix 1, available at www.arthroscopyjournal.org).[6,20-26,28,31-34,40-42,44,47,48,50-58] Nine studies were nonrandomized comparative studies and scored an average of 17.1/24 (range, 14-19) on the MINORS scale (Appendix 1, available at www.arthroscopyjournal.org).[19,27,30,35-38,43,45] Four studies were randomized comparative studies, and all scored 3/5 on the Jahad scale (Appendix 2, available at www.arthroscopyjournal.org).[29,39,46,49]

Demographics

Medial Opening Wedge High Tibial Osteotomy

A total of 35 studies were included for the MOW HTO cohort with a total of 3,079 patients included.[6,19,21,22,24,26,27,29,30,32-49,51-58] The patient population was 58.8% female (1,587/2,700; 3 studies did not differentiate by sex[21,24,51]), and the range of the mean age of the patients was 36.7 to 68.1 years (mean, 51.9 years). The range of the mean time to follow-up was 6 to 120 months (mean, 46.2 months). Study demographics are summarized in Table 1.

Lateral Closing Wedge High Tibial Osteotomy

A total of 19 studies were included for the LCW HTO cohort with a total of 1,442 patients included.[19-21,23,25,27,29-31,37-39,42,43,46,49,50,53,54] The patient population was 54.5% female (733/1,345; 1 study did not differentiate by sex[21]), and the range of the mean age of the patients was 37.2 to 60.2 years (mean, 51.9 years). The range of the mean time to follow-up was 6 to 240 months (mean, 75.7 months). Study demographics are summarized in Table 1.

Radiographic Outcomes

Medial Opening Wedge High Tibial Osteotomy

Across the studies, the main radiographic findings included the HKA angle, PTS, MPTA, patellar height, and aTFA. Sixteen studies reported on the HKA angle pre- and postoperatively.[24,29,32,34,36,38-40,43-45,54-58] The range of the mean preoperative HKA angle was 3.2° to 9.3° varus, and the range of the mean postoperative HKA angle was −0.7° to 6.4° valgus (Δ range, 7.2° to 11.9°) (Fig 2). All studies reported a significant improvement in the HKA angle. Nine studies reported on the PTS. The range of the mean preoperative PTS was 5.6° to 10.3°, and a range of the mean postoperative PTS was 6.2° to 11.7° (Δ range, −1.4° to 3.2°) (Fig 3).[6,21,37,39,42,49,53,54,57] Four studies reported a significant increase in PTS,[6,39,42,54] 4 studies reported no significant difference in PTS,[21,37,53,57] and 1 study reported a significant decrease.[49] Six studies reported on the MPTA pre- and postoperatively. The range of the mean preoperative MPTA was 77.1° to 85.6°, and the range of the mean postoperative MPTA was 90.6° to 92.3° (Δ range, 6.6° to 13.5°). All studies reported a significant increase in the MPTA. Four studies reported on the aTFA pre- and postoperatively. The range of the mean preoperative aTFA was 180.9° to 189.4°, and the range of the mean postoperative aTFA was 170.0° to 174.7° (Δ range, −17.0° to −9.7°).[19,27,42,48] All studies reported a significant decrease in aTFA. Five studies reported on patellar height using a variety of measurement techniques, including the CD index,[21] the Insall-Salvati index,[6] and BP index (Fig 4).[38,42,54] Four studies reported a significant decrease in patellar height,[6,21,42,54] and 1 study reported no significant difference.[38] All radiographic outcomes are summarized in Table 2.

Lateral Closing Wedge High Tibial Osteotomy

Seven studies reported on the HKA angle pre- and postoperatively.[20,23,29,38,39,43,54] The range of the mean preoperative HKA angle was 5.7° to 9.2° varus, and the range of the mean postoperative HKA angle was −2.8° to 3.2° of valgus (Δ range, 4.3° to 12.1°) (Fig 2).[20,23,29,38,39,43] All studies reported a significant improvement in the HKA angle. Posterior tibial slope was assessed in 9 studies. The range of the mean preoperative PTS was 5.2° to 10.8°, and the range of the mean postoperative PTS was 4.5° to 8.1° (Δ range, −4.5° to −0.7°) (Fig 3).[20,21,23,37,39,42,49,53,54] Eight studies reported a significant decrease in PTS,[21,23,37,39,42,49,53,54] and 1 study reported no significant difference in PTS.[20] Two studies reported on the MPTA pre- and postoperatively, and both reported significant decreases. One study reported a preoperative MPTA of 82.2° and a postoperative MPTA of 90.9°,[20] and the other study reported a preoperative MPTA of 75.3° and a postoperative MPTA of 89.5°.[37] Three studies reported on aTFA pre- and postoperatively. The range of the mean preoperative aTFA was 183.5° to 190.0°, and the range of the mean postoperative aTFA was 171.0° to 173.8° (Δ range, −19.0° to −11.2°).[19,27,42] All studies reported a significant decrease in the aTFA. Four studies reported on patellar height using the CD index[21] and BP index[38,42,54] (Fig 4). All studies reported no significant difference in patellar height. All radiographic outcomes are summarized in Table 2.

Patient-Reported Outcomes

Medial Opening Wedge High Tibial Osteotomy

The most reported PROs were the Lysholm, VAS, HSS, and Tegner scores. Seven studies reported on the Lysholm scores. The range of the mean preoperative Lysholm score was 48.8 to 83.7, and the range of the mean postoperative score was 70.6 to 96.18 (Δ range, 10.6 to 36) (Fig 5).[37,42,43,45-47,51] All studies reported

Table 1. Study Demographics

First Author, Year	Level of Evidence	Cohort	Patients (n)	Females (n)	Age (y)	Follow-Up (mo)
Agarwala 2016[19]	III	MOW	25	12	56.0	36.0
		LCW	23	10	55.0	36.0
Agostinone 2023[20]	IV	LCW	23	4	38.6	168.0
Amzallag 2013[21] and Ducat 2012[28]	III	MOW	224	—	52.0	6.0
		LCW	97	—	49.7	6.0
Astur 2020[22]	IV	MOW	66	13	47.5	24.0
Berruto 2020[23]	IV	LCW	82	35	55.3	142.8
Bonasia 2014[24]	IV	MOW	84	—	54.5	51.5
Constantin 2024[25]	IV	LCW	95	26	50.0	240.0
Corbeil 2021[26]	IV	MOW	84	30	50.0	37.2
Deie 2014[27]	IV	MOW	9	6	57.0	12.0
		LCW	12	9	57.0	12.0
Duivenvoorden 2014[29]	I	MOW	36	12	49.9	72.0
		LCW	45	18	49.5	72.0
Duivenvoorden 2017[30]	III	MOW	112	39	48.7	88.8
		LCW	354	151	49.4	127.2
Efe 2011[31]	IV	LCW	199	89	54.0	115.2
Giuseffi 2015[32]	IV	MOW	89	27	48.1	48.0
Han 2018[34]	III	MOW	88	67	56.7	38.5
Han 2019[33]	IV	MOW	209	180	56.4	24.0
Hoorntje 2023[35]	IV	MOW	84	18	55.0	24.0
Jacquet 2020[36]	III	MOW	50	22	49.3	44.4
Ji 2023[37]	III	MOW	300	216	50.4	19.9
		LCW	40	30	49.2	20.5
Jin 2020[58]	IV	MOW	339	248	56.0	115.2
Kim 2016[39]	I	MOW	30	21	54.3	12.0
		LCW	30	20	54.1	12.0
Kim 2020[38]	III	MOW	25	15	47.9	12.0
		LCW	28	19	51.8	12.0
LaPrade 2012[6]	IV	MOW	47	15	40.5	43.2
Lee 2021[40]	III	MOW	88	62	50.5	40.8
Liu 2019[41]	IV	MOW	38	9	42.7	108.0
Lu 2019[42]	III	MOW	36	25	56.7	86.1
		LCW	43	28	54.2	86.1
Majeed 2022[43]	III	MOW	27	24	54.6	72.0
		LCW	26	21	55.7	72.0
Miettinen 2022[44]	IV	MOW	167	29	48.1	92.4
Morin 2016[45]	II	MOW	21	7	51.9	12.0
Nerhus 2017[46]	II	MOW	35	15	51.3	24.0
		LCW	35	18	49.4	24.0
Orrego 2020[47]	IV	MOW	55	18	39.0	120.0
Otoshi 2021[48]	IV	MOW	74	55	68.1	32.9
Safdari 2023[49]	I	MOW	37	19	36.7	6.0
		LCW	36	19	37.2	6.0
Sasaki 2021[50]	IV	LCW	120	110	59.5	214.8
Screpis 2023[51]	III	MOW	71	—	—	52.6
Shim 2023[52]	IV	MOW	77	53	57.2	34.6
Song 2010[53]	III	MOW	90	69	51.0	26.7
		LCW	104	88	57.0	28.3
Song 2012[54]	III	MOW	50	40	57.9	42.4
		LCW	50	38	60.1	44.0
Tsai 2020[55]	IV	MOW	81	48	60.1	45.1
Whatling 2020[56]	II	MOW	19	2	51.2	13.8
Yang 2022[57]	III	MOW	212	171	56.3	97.2

LCW, lateral closing wedge; MOW, medial opening wedge.

significant improvements in the postoperative Lysholm scores. Six studies reported on the VAS scores. The range of the mean preoperative VAS score was 4.5 to 8.3, and the range of the mean postoperative score was 0 to 3.5 (Δ range, −6.0 to −2.6) (Fig 6).[22,24,29,39,45,49] All studies reported significant improvements in postoperative VAS scores. Six studies reported on HSS scores. The range of the mean preoperative HSS scores was 54.0 to 76.0, and the range of the mean postoperative HSS scores was 80.8 to 93.9 (Δ range, 8.5 to

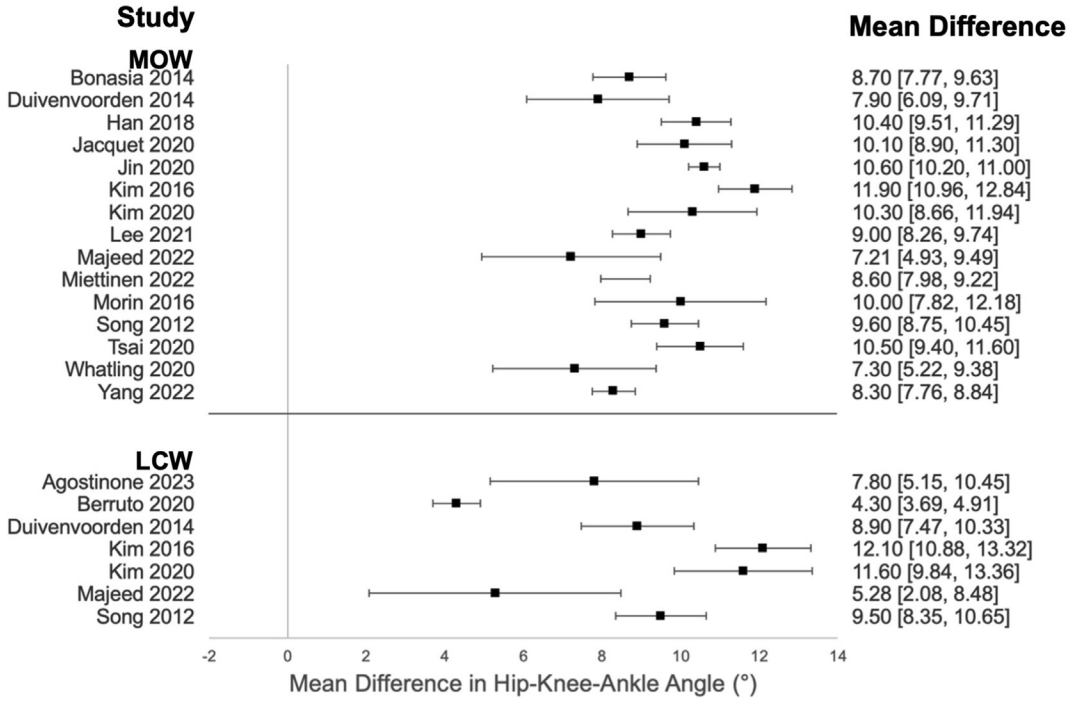

Fig 2. This forest plot depicts the mean difference in pre- to postoperative hip-knee-ankle (HKA) angle in degrees between studies that performed a medial opening wedge (MOW) high tibial osteotomy versus a lateral closing wedge (LCW) high tibial osteotomy. The mean difference and 95% confidence intervals (CIs) are listed on the right side of the plot. The study by Giuseffi et al.[32] was not included because a standard deviation or range was not provided.

28.0).[19,29,39,40,53,54] All studies reported significant improvements in postoperative HSS scores. Five studies reported on Tegner activity scores. The range of mean preoperative Tegner score was 1.4 to 3.1, and the mean postoperative score was 2.8 to 4.2 (Δ range, −0.3 to −2.8).[22,46,48,51,57] Three studies reported significant improvements in Tegner scores,[22,51,57] while the other 2 reported no significant improvements.[46,48] All PROs are summarized in Table 3.

Lateral Closing Wedge High Tibial Osteotomy

Four studies reported on Lysholm scores. The range of the mean preoperative Lysholm score was 47.3 to 79.6, and the range of the mean postoperative score was 73.8 to 96.0 (Δ range, 16.4 to 27.7) (Fig 5).[37,42,43,46] All studies reported significant improvements in the postoperative Lysholm scores. Five studies reported on the VAS scores. The range of the mean preoperative VAS score was 3.8 to 7.9, and the range of the mean postoperative score was 1.1 to 4.0 (Δ range, −6.3 to −2.3) (Fig 6).[20,23,29,39,49] All studies reported significant improvements in postoperative VAS scores. Six studies reported on the HSS scores. The range of the mean preoperative HSS score was 53.0 to 77.1, and the range of the mean postoperative HSS score was 75.0 to 93.7 (Δ range, 10.3 to 22.4).[19,23,29,39,53,54] All studies reported significant improvements in the postoperative HSS scores. Three studies reported on the Tegner scores. The range of the mean preoperative Tegner score was 1.3 to 3.0, and the mean postoperative score was 2.8 to 4.0 (Δ range, 0.7 to 1.5).[20,23,46] Two study reported significant improvements in Tegner scores,[20,23] while the other study reported no significant improvements.[46] All PROs are summarized in Table 3.

Survivorship and Complications

Medial Opening Wedge High Tibial Osteotomy

Thirteen studies reported on outcomes related to progression to TKA or UKA. Two studies reported no progression to TKA or UKA,[36,46] and the other 11 studies reported progression to TKA or UKA with the range of conversion of 3.6% to 34.2% of total patients.[6,24,26,29,30,32,35,41,44,47,58] Five studies reported on survivorship at 10 years with a range of survivorship from 78% to 94%.[26,30,44,47,58] Thirteen studies reported on delayed or nonunion and reported a range of 0.5% to 8.0% of total patients.[6,19,29,30,32,33,35,36,41,43,46,49,58] Fourteen studies reported on hardware removal and reported a range of 0.6% to 75.0% of total patients.[6,19,24,26,29,30,32,33,35,36,41,44,46,58] The most common operative complications were lateral hinge fractures and lateral tibial plateau fractures. Ten studies reported on lateral hinge fractures and reported a range of 2.1% to 16.0% of total patients.[6,24,29,32,33,36,39,42,44,49] Six studies reported on plateau fractures and reported a

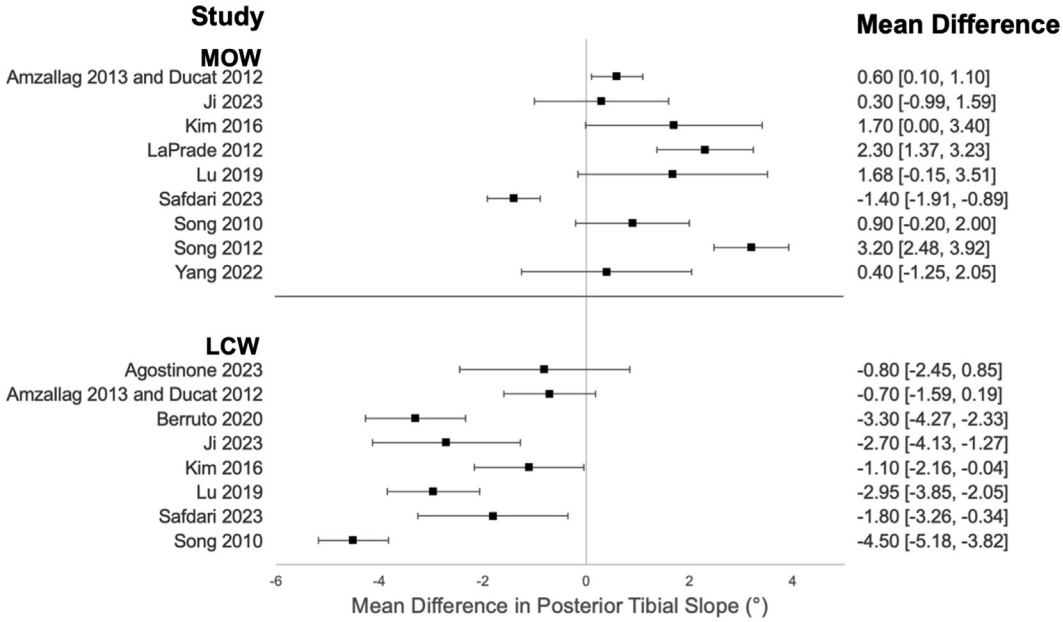

Fig 3. This forest plot depicts the mean difference in pre- to postoperative posterior tibial slope in degrees between studies that performed a medial opening wedge (MOW) high tibial osteotomy versus a lateral closing wedge (LCW) high tibial osteotomy. The mean difference and 95% confidence intervals (CIs) are listed on the right side of the plot.

range of 0.9% to 6.7% of total patients.[24,32,33,53,57,58] All complications are summarized in Table 4.

Lateral Closing Wedge High Tibial Osteotomy

Eight studies reported on outcomes related to progression to TKA or UKA with the range of conversion of 2.9% to 56.8% of total patients.[20,23,25,29-31,46,49] Six studies reported on survivorship at 10 years with a range from 75.0% to 96.7%.[20,23,25,30,31,49] Six studies reported on delayed or nonunion and reported a range of 2.4% to 17.4% of total patients.[19,20,23,30,31,46] Five studies reported on hardware removal and reported a range of 1.2% to 48.0% of total patients.[23,29,30,43,46] The most common operative complication was peroneal nerve palsy. Seven studies reported on peroneal nerve palsy and reported a range of 1.2% to 8.7% of total patients.[19,23,29-31,39,53] All complications are summarized in Table 4.

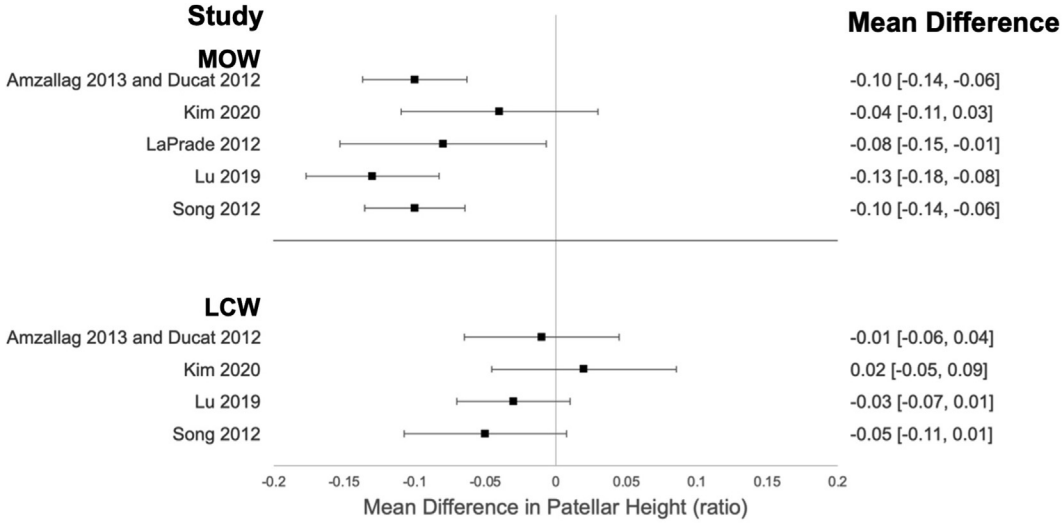

Fig 4. This forest plot depicts the mean difference in pre- to postoperative patellar height as a ratio between studies that performed a medial opening wedge (MOW) high tibial osteotomy versus a lateral closing wedge (LCW) high tibial osteotomy. The mean difference and 95% confidence intervals (CIs) are listed on the right side of the plot.

Table 2. Radiographic Outcomes for Medial Opening Wedge and Lateral Closing Wedge High Tibial Osteotomy Studies

			HKA Angle (°)		PTS (°)		MPTA (°)		Patellar Height (Ratio)	
First Author, Year	Cohort	Patients	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Agarwala 2016[19]	MOW	25								
Amzallag 2013[21] and Ducat 2012[28]	MOW	224			5.6	6.2			0.98 (CD)	0.88*
Bonasia 2014[24]	MOW	84	−7.6	1.1*						
Deie 2014[27]	MOW	9								
Duivenvoorden 2014[29]	MOW	36	−6.6	1.3*						
Giuseffi 2015[32]	MOW	89	−3.2	6.4*						
Han 2018[34]	MOW	88	−7.1	3.3*						
Jacquet 2020[36]	MOW	50	−8.5	1.6*						
Ji 2023[37]	MOW	300			10.2	10.5	77.1	90.6*		
Jin 2020[58]	MOW	339	−7.2	3.4						
Kim 2016[39]	MOW	30	−9.1	2.8*	7.8	9.5*				
Kim 2020[38]	MOW	25	−9.3	1.0*					0.78 (BP)	0.74
LaPrade 2012[6]	MOW	47			9.4	11.7*			1.03 (IS)	0.95*
Lee 2021[40]	MOW	88	−6.6	2.4*			84.2	91.2*		
Lu 2019[42]	MOW	36			7.4	9.5*			0.85 (BP)	0.72*
Majeed 2022[43]	MOW	27	−6.9	0.3*						
Miettinen 2022[44]	MOW	167	−5.8	2.8*			85.6	92.2*		
Morin 2016[45]	MOW	21	−7.0	3.0*						
Otoshi 2021[48]	MOW	74								
Safdari 2023[49]	MOW	37			10.3	8.9*				
Shim 2023[52]	MOW	77					83.9	91.4*		
Song 2010[53]	MOW	90			9.5	10.4				
Song 2012[54]	MOW	50	−7.6	2.0*	8.3	11.5*			0.8 (BP)	0.7*
Tsai 2020[55]	MOW	81	−8.1	2.4*			84.2	92.3*		
Whatling 2020[56]	MOW	19	−8.0	−0.7*						
Yang 2022[57]	MOW	212	−6.8	1.5*	8.7	9.1	85.5	92.2*		
Agarwala 2016[19]	LCW	23								
Agostinone 2023[20]	LCW	23	−6.2	1.6*	6.0	5.2	82.2	90.9*		
Amzallag 2013[21] and Ducat 2012[28]	LCW	97			5.2	4.5*			1.07 (CD)	1.06
Berruto 2020[23]	LCW	82	−6.9	−2.6*	10.1	6.8*				
Deie 2014[27]	LCW	12								
Duivenvoorden 2014[29]	LCW	45	−5.7	3.2*						
Ji 2023[37]	LCW	40			10.8	8.1*	75.3	89.5*		
Kim 2016[39]	LCW	30	−9.2	2.9*	7.1	6.0*				
Kim 2020[38]	LCW	28	−9.1	2.5*					0.81 (BP)	0.83
Lu 2019[42]	LCW	43			7.6	4.7*			0.84 (BP)	0.81
Majeed 2022[43]	LCW	26	−8.1	−2.8*						
Safdari 2023[49]	LCW	36			8.1	6.3*				
Song 2010[53]	LCW	104			9.1	4.6*				
Song 2012[54]	LCW	50	−7.3	2.2*	8.2	5.0*			0.79 (BP)	0.74

NOTE. HKA angles are marked in negative numbers for varus alignment and positive numbers for valgus alignment. The parentheses in the preoperative column for the patellar height designate which measurement technique was used as defined below.

BP, Blackburne-Peel; CD, Caton-Deschamps; HKA, hip-knee-ankle; IS, Insall-Salvati; LCW, lateral closing wedge; MOW, medial opening wedge; MPTA, medial proximal tibial angle; Postop, postoperative; Preop, preoperative; PTS, posterior tibial slope.

*Significantly different from preoperative value ($P \leq .05$).

Discussion

The most important finding from this systematic review was that there were significantly improved PROs for both MOW and LCW HTO to treat symptomatic medial compartment osteoarthritis with varus alignment. For radiographic outcomes, MOW and LCW HTO both reported significant improvements in HKA angles, MOW HTO had significant increases in PTS, LCW HTO had significant decreases in PTS, MOW HTO had significant decreases in patellar height, and LCW HTO had no significant differences in patellar height. For complications and failures, both MOW and LCW HTO had comparable survivorship, delayed or nonunion, and hardware removal; however, MOW HTO had more intraoperative complications of lateral hinge or lateral tibial plateau fractures, while LCW HTO had more intraoperative complications of peroneal nerve palsy. Overall, both techniques are effective at treating medial compartment osteoarthritis with varus alignment, but both techniques have certain risk factors that should be considered.

The PROs analyzed for this study were the Lysholm, VAS, HSS, and Tegner scores. For both MOW and LCW HTO, PROs were significantly improved between pre-

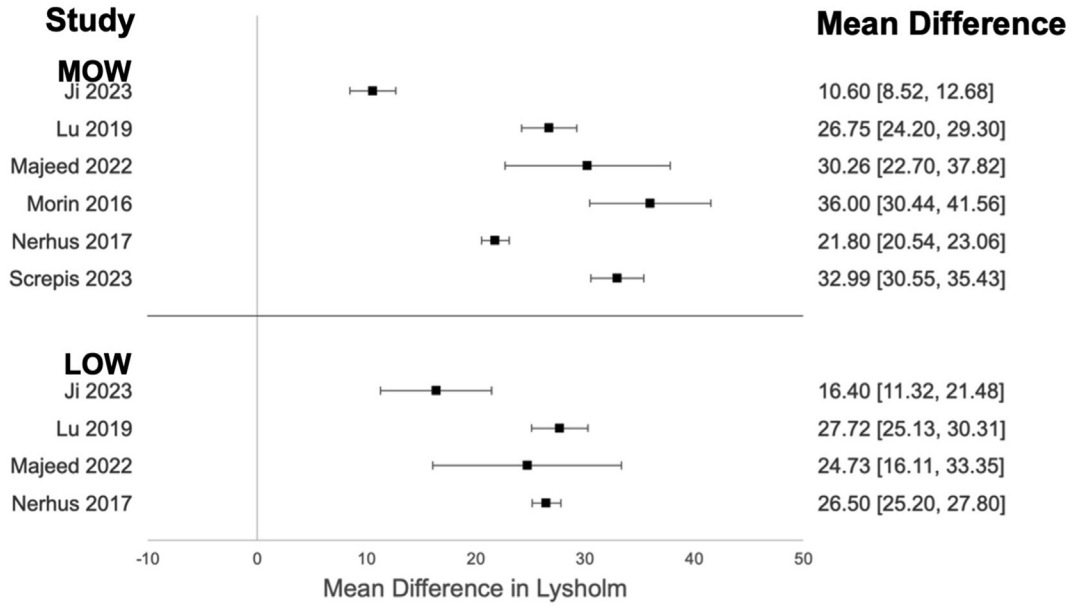

Fig 5. This forest plot depicts the mean difference in pre- to postoperative Lysholm score between studies that performed a medial opening wedge (MOW) high tibial osteotomy versus a lateral closing wedge (LCW) high tibial osteotomy. The mean difference and 95% confidence intervals (CIs) are listed on the right side of the plot.

and postoperative outcomes. Only 1 study in the MOW cohort was below the MCID of 13.0 for the Lysholm score,[37] and all studies were above the patient acceptable symptomatic state score of 70.0 for the Lysholm score.[59] The 1 study below the MCID of 13.0 for the Lysholm had a very high preoperative score of 83.7, and those patients still reported a significant improvement to a final score of 94.3.[37] For the VAS, 1 study from the MOW HTO cohort and 1 study from the LCW HTO cohort were below the MCID of 2.7,[60] and these were both from Duivenvoorden et al.,[29] who reported on MOW and LCW HTO groups. Four studies in this systematic review reported on the Lysholm scores for both MOW and LCW HTO, and all of these studies reported no significant

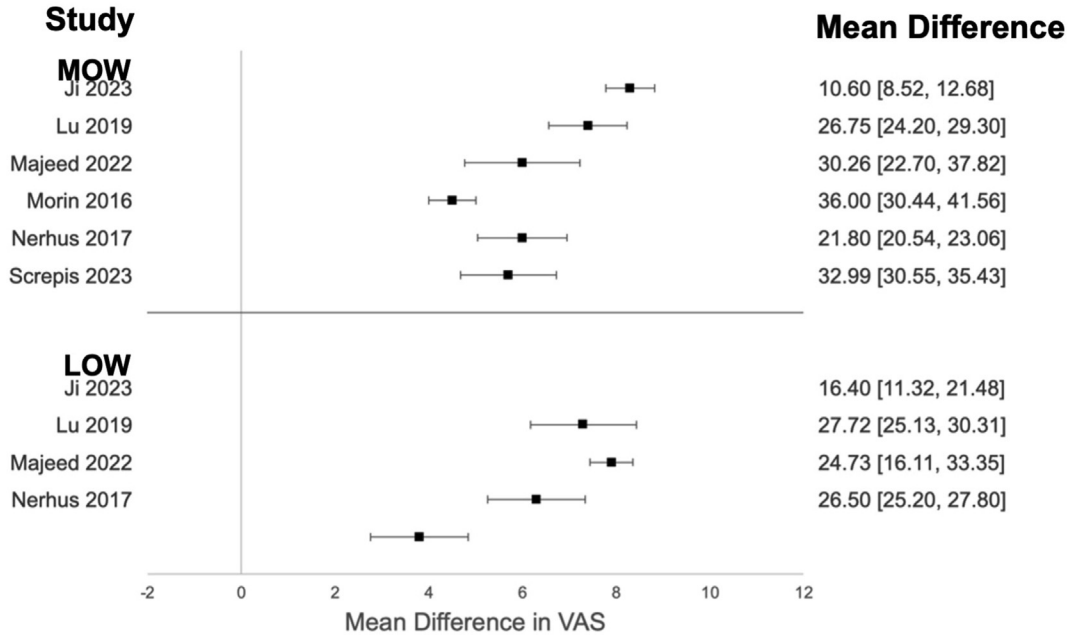

Fig 6. This forest plot depicts the mean difference in pre- to postoperative visual analog scale scores between studies that performed a medial opening wedge (MOW) high tibial osteotomy versus a lateral closing wedge (LCW) high tibial osteotomy. The mean difference and 95% confidence intervals (CIs) are listed on the right side of the plot.

Table 3. Patient-Reported Outcomes for the Medial Opening Wedge and Lateral Closing Wedge High Tibial Osteotomy Studies

			Lysholm		VAS		HSS		Tegner	
First Author, Year	Cohort	Patients	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Agarwala 2016[19]	MOW	25					54.0	82.0*		
Astur 2020[22]	MOW	66			8.3	3.5*			1.4	4.2*
Bonasia 2014[24]	MOW	84			7.4	3.5*				
Duivenvoorden 2014[29]	MOW	36			6.0	3.4*	72.3	80.8*		
Ji 2023[37]	MOW	300	83.7	94.3*						
Kim 2016[39]	MOW	30			4.5	1.5*	76.0	92.2*		
Lee 2021[40]	MOW	88					73.5	89.2*		
Lu 2019[42]	MOW	36	63.6	90.4*						
Majeed 2022[43]	MOW	27	49.4	79.7*						
Morin 2016[45]	MOW	21	60.0	96.0*	6.0	0.0*				
Nerhus 2017[46]	MOW	35	48.8	70.6*					2.2	2.9
Orrego 2020[47]	MOW	55	68.0	95.0*						
Otoshi 2021[48]	MOW	74							3.1	2.8
Safdari 2023[49]	MOW	37			5.7	2.7*				
Screpis 2023[51]	MOW	71	63.2	96.2*					2.9	4.0*
Song 2010[53]	MOW	90					73.8	93.0*		
Song 2012[54]	MOW	50					74.8	93.9*		
Yang 2022[57]	MOW	212							2.1	4.2*
Agarwala 2016[19]	LCW	23					53.0	75.0*		
Agostinone 2023[20]	LCW	23			7.3	4.0*			3.0	4.0*
Berruto 2020[23]	LCW	82			7.9	1.6*	70.8	93.2*	1.3	2.8*
Duivenvoorden 2014[29]	LCW	45			6.3	4.0*	71.5	81.8*		
Ji 2023[37]	LCW	40	79.6	96.0*						
Kim 2016[39]	LCW	30			3.8	1.1*	77.1	93.7*		
Lu 2019[42]	LCW	43	62.4	90.2*						
Majeed 2022[43]	LCW	26	51.1	75.8*						
Nerhus 2017[46]	LCW	35	47.3	73.8*					2.4	3.1
Safdari 2023[49]	LCW	36			6.3	3.2*				
Song 2010[53]	LCW	104					73.4	91.8*		
Song 2012[54]	LCW	50					72.1	92.6*		

HSS, Hospital for Special Surgery; LCW, lateral closing wedge; MOW, medial opening wedge; Postop, postoperative; Preop, preoperative; VAS, visual analog scale.

*Significantly different from preoperative value ($P \leq .05$).

difference between the mean improvement of Lysholm scores between MOW and LCW HTO.[37,42,43,46] The same was true for the 2 studies that reported on the VAS scores for both MOW and LCW osteotomies.[39,49] The HSS scores had significant improvements across all studies for both MOW and LCW HTO; however, no MCID was found for HSS scores. Overall, the weakest improvements in PROs were for the Tegner activity scores, in which 2 of 5 MOW HTO[46,47] and 1 of 3 LCW HTO[46] studies did not report any significant improvement. This suggests that return to activity (what the Tegner score measures), especially for the older population in whom MOW and LCW HTO typically occur, is challenging. However, overall, the PROs reported significant improvement for patients undergoing MOW or LCW HTO.

For the radiographic outcomes, the HKA angle was the most reported outcome measurement overall for both MOW and LCW HTO studies. All studies in this systematic review reported a significant reduction in varus angle postoperatively. Four studies reported on HKA angles for both MOW and LCW HTO, and only 1 study by Majeed et al.[43] reported a significant difference in the pre- to postoperative change in HKA angle, with the MOW HTO group reporting a change of 7.2° and the LCW HTO group reporting a significantly decreased change of 5.3°. The 3 other studies reported no significant difference between the MOW and LCW HTO groups.[38,39,54] For PTS, 4 of the 9 MOW HTO studies[6,39,42,54] reported a significant increase in PTS while 8 of the 9 LCW HTO studies[21,23,37,39,42,49,53,54] reported a significant decrease in PTS. These findings suggest that for a patient with an elevated PTS, an LCW HTO should be considered if a decrease in PTS is desired (such as for anterior cruciate ligament–deficient knees) or, at the very least, a posteriorly placed MOW HTO plate to avoid increased PTS. For patients with a low PTS and a desire to increase slope (such as for a posterior cruciate ligament–deficient knee), an MOW HTO should be considered with a more anterior plate or an LCW HTO with more bone taken posteriorly than anteriorly. For patellar height, all 4 LCW HTO studies[21,38,42,54] reported no significant difference in patellar height measurements, whereas 4 of 5 MOW

Table 4. Complications for the Medial Opening Wedge and Lateral Closing Wedge High Tibial Osteotomy Studies

First Author, Year	Cohort	Patients	Progression to TKA/UKA	Delayed Union	Survivorship, %	Hardware Removal	Hinge Fracture	Plateau Fracture	Nerve Injury
Agarwala 2016[19]	MOW	25		2 (8)		1 (4)			
Bonasia 2014[24]	MOW	84	6 (7.1)			22 (26.2)	10 (11.9)	2 (2.4)	
Corbeil 2021[26]	MOW	84	14 (16.7)		91.9	43 (51.2)			
Duivenvoorden 2014[29]	MOW	36	3 (8.3)	2 (5.6)		27 (75)	2 (5.6)		
Duivenvoorden 2017[30]	MOW	112	8 (7.1)	4 (3.6)	90.0	79 (70.5)			
Giuseffi 2015[32]	MOW	89	7 (7.9)	6 (6.7)		10 (11.2)	5 (5.6)	6 (6.7)	
Han 2019[33]	MOW	209		1 (0.5)		13 (6.2)	29 (13.9)	3 (1.4)	
Hoorntje 2023[35]	MOW	84	3 (3.6)	2 (2.4)		61 (72.6)			
Jacquet 2020[36]	MOW	50	0 (0.0)	1 (2)		11 (22)	8 (16)		
Jin 2020[58]	MOW	339	13 (3.8)	3 (0.9)	87.1	3 (0.9)		12 (3.5)	11 (3.2)
Kim 2016[39]	MOW	30					1 (3.3)		
LaPrade 2012[6]	MOW	47	2 (4.3)	2 (4.3)		9 (19.1)	1 (2.1)		
Liu 2019[41]	MOW	38	13 (34.2)	1 (2.6)		4 (10.5)			
Lu 2019[42]	MOW	36					2 (5.6)		5 (13.9)
Majeed 2022[43]	MOW	27		1 (3.7)					
Miettinen 2022[44]	MOW	167	32 (19.2)		78.0	1 (0.6)	7 (4.2)		
Nerhus 2017[46]	MOW	35	0 (0.0)	1 (2.9)		8 (22.9)			
Orrego 2020[47]	MOW	55	3 (5.5)		94.0				
Safdari 2023[49]	MOW	37		1 (2.7)			2 (5.4)		
Song 2010[53]	MOW	90						6 (6.7)	
Yang 2022[57]	MOW	212						2 (0.9)	3 (1.4)
Agarwala 2016[19]	LCW	23		4 (17.4)					2 (8.7)
Agostinone 2023[20]	LCW	23	5 (21.7)	1 (4.3)	82.6				
Berruto 2020[23]	LCW	82	16 (19.5)	2 (2.4)	92.0	1 (1.2)			1 (1.2)
Constantin 2024[25]	LCW	95	54 (56.8)		77.0				
Duivenvoorden 2014[29]	LCW	45	10 (22.2)			19 (42.2)	1 (2.2)		1 (2.2)
Duivenvoorden 2017[30]	LCW	354	73 (20.6)	12 (3.4)	75.0	170 (48)			14 (4)
Efe 2011[31]	LCW	199	36 (18.1)	17 (8.5)	84.0				6 (3)
Kim 2016[39]	LCW	30							1 (3.3)
Lu 2019[42]	LCW	43					2 (4.7)		
Majeed 2022[43]	LCW	26				1 (3.8)			
Nerhus 2017[46]	LCW	35	1 (2.9)	6 (17.1)		4 (11.4)			
Sasaki 2021[50]	LCW	120	16 (13.3)		96.7				
Song 2010[53]	LCW	104							7 (6.7)

NOTE. All values are presented as number (%) of the total patients. The percent survivorship is for 10-year survivorship.

LCW, lateral closing wedge; MOW, medial opening wedge; Postop, postoperative; Preop, preoperative; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

HTO[6,21,42,54] studies reported significant decreases in patellar height. Overall, both MOW and LCW HTO are effective at reducing varus alignment for HKA angles, but MOW HTOs tend to lead to an increase in PTS and a decrease in patellar height, whereas LCW HTOs tend to lead to a decrease in PTS and no change in patellar height.

Furthermore, both MOW HTO and LCW HTO techniques reported similar 10-year survivorship for non- or delayed unions and hardware removal; however, MOW HTO had higher rates of hinge and intra-articular lateral tibial plateau fractures, and LCW HTO had a higher rate of peroneal nerve palsy. Although there were no determinations about which HTO technique leads to increased conversion to TKA, there was a slightly higher conversion to TKA in the LCW groups compared to MOW groups. Three studies reported on conversion to TKA for both MOW and LCW HTOs. One study by Duivenvoorden et al.[29] reported a conversion to TKA of 8.3% for the MOW HTO group and 22.2% for the LCW HTO group. Another study by Duivenvoorden et al.[30] reported similar outcomes with a conversion to TKA of 7.1% for the MOW HTO group and 20.6% for the LCW HTO group. A separate study by Nerhus et al.[46] reported no conversions to TKA for the MOW HTO group and 1 conversion for the LCW HTO group (2.9%). The 10-year survivorship had similar ranges for both the MOW HTO and LCW HTO, suggesting that the survivorship may be determined more by the patients, level of arthritis, and indications rather than the specific HTO technique. For intraoperative complications, hinge and intra-articular lateral tibial plateau fractures were more common in MOW HTO studies, with 13 of 35 (37.1%) studies reporting on either a hinge and/or plateau fracture.[6,24,29,32,33,36,39,42,44,49,53,57,58] Only 2 LCW HTO studies reported any post-HTO fractures, with Duivenvoorden et al.[29] reporting a fracture in 1 of 354

patients (0.3%) and Lu et al.[42] reporting a fracture in 2 of 43 patients (4.7%). Nerve injuries were more common in LCW HTO studies, with 7 of 19 (36.8%) studies reporting a peroneal nerve palsy (either temporary or permanent).[19,23,29-31,39,53] Only 3 MOW HTO studies reported any nerve injury, all of which reported sensory nerve injuries of the saphenous nerve.[42,57,58] A sensory saphenous nerve injury was reported by Lu et al.[42] in 5 of 36 patients (13.9%), Yang et al.[57] in 3 of 212 patients (1.4%), and Jin et al.[58] in 11 of 339 patients (3.2%). These findings suggest that both MOW HTO and LCW HTO have comparable 10-year survivorship with potentially slightly less conversion to TKA for MOW HTOs. Intraoperative complications vary, with fractures more likely in the MOW HTO group and nerve injuries more common in the LCW HTO group.

Limitations

This study is not without potential complications. First, due to significant heterogeneity between the outcomes reported by the studies, a comparative analysis could not be performed. Some studies only reported on short-term radiographic outcomes, where others reported on long-term PROs. Additionally, all of the studies were low to moderate quality according to the MINORS and Jadad criteria. More high-quality comparative studies between MOW and LCW HTOs would strengthen a future systematic review. Also, many studies listed that they had no complications or only reported <2-year follow-up, which is not an optimal representation of outcomes for these types of osteotomies. All together, these limitations prevented us from pooling data or performing a meta-analysis.

Conclusions

This systematic review found comparable HKA angle correction and PROs between patients undergoing MOW or LCW HTOs to treat medial compartment osteoarthritis. Survivorship at 10 years was comparable between MOW and LCW HTOs; however, some MOW and LCW HTO comparison studies reported higher conversion to TKA for LCW HTO. Medial opening wedge HTO typically results in an increased PTS, decreased patellar height, and tibial fractures, while LCW HTO typically results in decreased PTS, no change in patellar height, and common peroneal nerve injuries.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: C.M.L. has received speaking and lecture fees from Foundation Medical and Evolution Surgical; has a family member who is a consultant or advisor for Ossur Americas, Smith & Nephew, Linvatec Europe, and Responsive Arthroscopy; and has a family member receives funding grants from Ossur Americas, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine. R.F.L. is a consultant or advisor for Ossur Americas, Smith & Nephew, Linvatec Europe, and Responsive Arthroscopy and receives funding grants from Ossur Americas, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine. All other authors (L.V.T., D.L., T.K.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. MINORS Scoring for Nonrandomized Comparative and Noncomparative Studies

First Author, Year	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss to follow-up less than 5%	Prospective calculation of the study size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analyses	Sum
Agarwala 2016	2	1	0	2	1	2	2	0	1	2	2	1	16
Agostinone 2023	2	1	2	2	1	2	2	2					14
Amzallag 2013	2	2	2	2	0	2	2	0					12
Ducat 2012	2	2	2	2	0	2	2	0					12
Astur 2020	2	2	2	2	0	2	1	2					13
Berruto 2020	2	2	0	2	0	2	1	2					11
Bonasia 2014	2	2	0	2	0	2	1	0					9
Constantin 2024	2	2	2	2	0	2	2	0					12
Corbeil 2021	2	2	0	2	0	2	1	0					9
Deie 2014	2	1	0	2	2	1	2	0	1	2	2	1	16
Duivenvoorden 2017	1	1	0	2	0	2	1	1	1	2	1	2	14
Efe 2011	2	1	0	2	0	2	2	0					9
Giuseffi 2015	2	2	0	2	0	2	1	2					11
Han 2018	2	2	0	2	0	2	1	0					9
Han 2018 − 2	2	2	1	2	0	2	1	0					10
Hoorntje 2023	2	2	2	2	0	2	1	1	1	2	1	2	18
Jacquet 2020	2	1	0	2	0	2	2	2	1	2	2	2	18
Ji 2023	2	1	0	2	2	1	2	2	1	2	2	2	19
Jin 2020	2	1	0	2	0	2	1	0					8
Kim 2020	2	1	0	2	0	2	2	0	1	2	2	2	16
LaPrade 2012	2	2	2	2	2	2	1	0					13
Lee 2021	2	2	0	2	2	2	2	0					12
Liu 2019	2	1	1	2	0	2	1	0					9
Lu 2019	2	1	0	2	0	2	2	0					9
Majeed 2022	2	2	2	2	0	2	1	0	1	2	2	2	18
Miettinen 2022	2	2	0	2	0	2	2	0					10
Morin 2016	2	2	2	2	0	2	2	1	2	1	1	2	19
Orrego 2020	2	2	0	2	0	2	2	0					10
Otoshi 2021	2	1	0	2	0	2	1	0					8
Sasaki 2021	2	1	0	2	0	2	1	0					8
Screpis 2023	2	1	0	2	0	2	2	2					11
Shim 2023	2	1	0	2	1	2	2	0					10
Song 2010	2	2	0	2	0	2	2	0					10
Song 2012	2	1	0	2	0	2	2	2					11
Tsai 2020	2	2	0	2	0	2	2	0					10
Whatling 2020	2	1	0	2	0	1	2	1					9
Yang 2022	2	1	1	2	2	2	2	0					12

Appendix 2. Jadad Scale for Randomized Studies

First Author, Year	Was the study described as randomized? (1 point)	Were the methods for randomization appropriate? (+1 for yes, −1 for no)	Was the study described as double blind? (1 point)	Was the method for achieving double blind appropriate? (+1 for yes, −1 for no)	Was there a description of the withdrawals and dropouts? (1 point)	Sum
Duivenvoorden 2014	1	1	0	0	1	3
Kim 2016	1	1	0	0	1	3
Nerhus 2017	1	1	0	0	1	3
Safdari 2023	1	1	0	0	1	3