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Good long-term survival and patient-reported outcomes after high tibial osteotomy for medial compartment osteoarthritis

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Abstract

The lateral closing and medial opening wedge high tibial osteotomy can correct a varus malalignment of the knee caused by medial compartment osteoarthritis. These procedures have produced great short-term and mid-term results. As no systematic review has examined their long-term results yet, the goal of this article was to compare the results of all articles about lateral closing and medial opening wedge high tibial osteotomies, published after the year 2000, with a mean follow-up of more than 10 years. A systematic search of the Medline, Web of Science and Cochrane databases resulted in the inclusion of 30 articles. All these studies combined examined the results of 7087 high tibial osteotomies in a total of 6636 patients after a mean follow-up of more than 10 years. Primary outcome measures were the survival rate of the osteotomy, functional scores, patient satisfaction and pain scores. Secondary outcome measures were alignment correction and the identification of factors influencing the survival of the osteotomy. The 5-year, 10-year, 15-year and 20-year survival rates, respectively, ranged from 86 to 100%, 64–97.6%, 44–93.2% and 46–85.1%. The subjective scoring systems showed an improvement postoperatively that was maintained until final follow-up. The anatomical and mechanical tibiofemoral axis were, respectively, corrected to a mean of 7.3°–13.8° of valgus and 0.6°–4° of valgus. The results of the articles evaluating the influence of potential risk factors were contradictory. Despite the low quality of the available evidence, the lateral closing and medial opening wedge high tibial osteotomy seem to remain valid long-term treatment options for patients with painful varus malalignment caused by isolated medial compartment osteoarthritis of the knee. The available results indicate that the need for arthroplasty could be delayed for more than 15 years in the majority of patients. However, higher-quality studies are needed to confirm these findings. As a systematic review is assigned a level of evidence equivalent to the lowest level of evidence used from the analyzed manuscripts, the level of evidence of this systematic review is IV.

Keywords Knee · Osteoarthritis · Gonarthrosis · High tibial osteotomy · Varus · Long-term outcomes

Introduction

Knee osteoarthritis most commonly affects the medial compartment, as the load on this compartment in healthy knees is about 2.5 times greater than on the lateral side [3, 33]. This can lead to the gradual development of a varus malalignment and a subsequent shift of the weightbearing line to pass more medially through the tibial plateau. A further increase of the load on the medial compartment and decrease of the load on the lateral compartment ensues [44].

Specific surgical options exist for medial compartment osteoarthritis of the knee, amongst which high tibial osteotomy and unicompartmental knee arthroplasty. The two most popular osteotomy techniques are the lateral closing wedge and medial opening wedge high tibial osteotomy [11, 13]. The purpose of these procedures is to redirect the weightbearing axis to a neutral or slightly more lateral position, aiming to interrupt and potentially reverse the pathological changes in the medial compartment [28]. Short- and mid-term results obtained with high tibial osteotomies are good to excellent, but the results gradually deteriorate over time [7, 12, 14, 34]. The excellent results of the unicompartmental knee arthroplasty resulted in a decline in the use of high tibial osteotomies [8, 57]. However, current developments

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like tissue engineering and meniscal transplants might revive the interest in the latter as the alignment of the knee will influence their results [31, 56].

The question remains whether there continues to be a place for isolated high tibial osteotomies as treatment for varus knees secondary to medial compartment osteoarthritis and whether the long-term results can justify their use. Many studies refer to the long-term results of a select number of publications. However, no prior study has systematically collected all the available long-term results.

Hence, the goal of this study is to systematically look at the published long-term results of the lateral closing and medial opening wedge technique. Less frequently performed techniques (e.g., the dome osteotomy) will not be discussed.

The hypothesis of this systematic review is that an isolated high tibial osteotomy remains a valid alternative for a unicompartmental knee arthroplasty, with good long-term outcomes in carefully selected patients suffering from medial compartment osteoarthritis of the knee.

Materials and methods

Search strategy

A systematic search of the Medline, Web of Science and Cochrane databases was conducted. The aim was to identify all the articles published between January 1, 2000 and February 20, 2020 presenting the long-term results of lateral closing and/or medial opening wedge high tibial osteotomies. The cut-off was arbitrarily set at the year 2000 to avoid potential skewing of the results by studies of osteotomies performed with early, less standardized techniques using less stable fixation material.

The Medline database was searched using the terms 'high tibial osteotomy', 'varus gonarthrosis' and 'long term results', which yielded 69 articles.

The Web of Science database was searched using 'high tibial osteotomy osteoarthritis long term results' as search criterium. With this method, 250 articles were identified.

The search strategy for the Cochrane database for systematic reviews was 'high tibial osteotomy', which yielded 3 reviews. The detailed search strategy can be found in Fig. 1. The articles initially identified with these three search methods were subsequently screened for inclusion in this systematic review in the following order: publication date, language, title, abstract and full text using the inclusion and exclusion criteria listed in Table 1.

Data collection

Two of the authors independently used the above strategy to screen the obtained articles for eligibility. A third author was consulted in case of disagreement. Thirty articles were eventually included, as can be seen in Fig. 1. All of them have a level of evidence of III or IV. Five articles present results of the medial opening wedge technique [21, 22, 24, 41, 43]. Nineteen articles report solely on the lateral closing wedge technique [1, 6, 9, 16, 18–20, 25, 26, 29, 30, 32, 36, 38, 39, 46, 48, 50, 51]. Six articles share the results of the medial opening and lateral closing wedge technique by either comparing or combining the outcomes [4, 15, 35, 40, 42, 52].

All these studies combined present the results of 7087 high tibial osteotomies performed between 1970 and 2012 in a total of 6636 patients.

Primary outcome measures were the survival rate of the osteotomy, functional scores (e.g., the Oxford Knee Score, the Hospital for Special Surgery score, the Knee Society Score, etc.), patient satisfaction and pain scores. Secondary outcome measures were the alignment correction and identification of factors influencing the survival.

Risk of bias

Every included study was subjected to a risk of bias analysis, which was done independently by two of the authors. A third author was consulted in case of disagreement. As none of the included studies were randomized and most lacked a control group, the ROBINS-I tool for uncontrolled before–after studies was chosen as evaluation method [49]. The results are presented in Table 2.

Results

Primary outcome measures

1. Survival

   The survival rate was generally defined as the percentage of high tibial osteotomies that had not been converted to arthroplasty in function of time. Three articles broadened the definition of failure by adding re-osteotomy to it [19, 26, 41]. Akizuki et al. also labeled an HSS score of less than 70 as failure [1]. Polat et al. considered survival as the survival of the native joint, with radiological destruction without conversion to arthroplasty also being noted as failure [40].

   Twenty-two articles reported a Kaplan–Meier survival analysis [1, 6, 15, 16, 18–20, 22, 25, 26, 29, 30, 35, 38, 41–43, 46, 48, 50–52]. The survival in the eight articles without a Kaplan–Meier analysis was calculated by dividing the number of high tibial osteotomies not converted to arthroplasty at final follow-up by the number of osteotomies included in the study [4, 9, 21, 24, 32, 36, 39, 40].

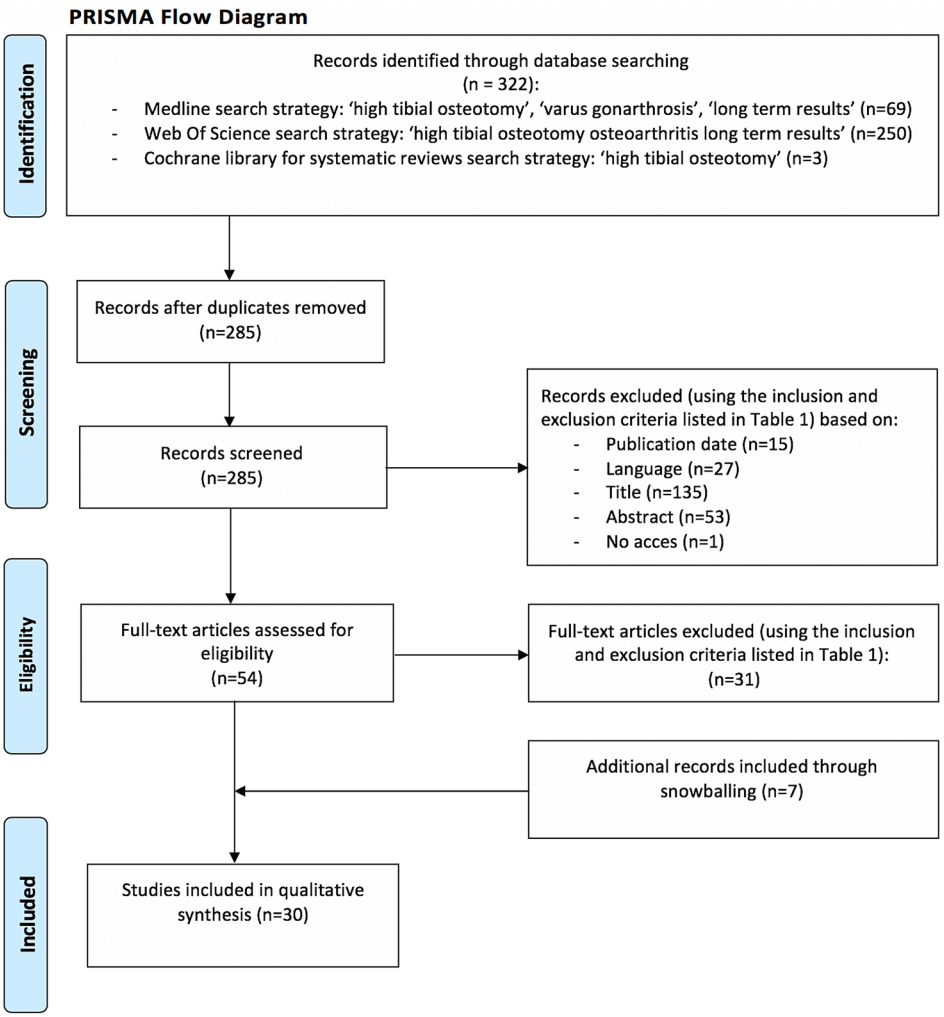

Fig. 1 Preferred reporting items for systematic reviews and meta-analyses flow diagram

Table 1 Summary of inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Medial opening wedge and/or lateral closing wedge high tibial osteotomy	Published before January 1, 2000
Varus malalignment	Non-English papers
Medial compartment osteoarthritis	Biomechanical studies
Information about survival	Book chapters
Mean length of follow-up > 10 years	Technique other than standard lateral closing wedge or medial opening wedge technique
Representative study population	Other cause for osteotomy than osteoarthritis in > 15% of patients
Articles identified with the snowballing method meeting all the criteria	Articles about high tibial osteotomies combined with other major procedures (e.g., ligament reconstruction, femoral osteotomy, etc.)

The 5-year, 10-year and 15-year survival rate in the studies, respectively, ranged from 86 to 100%, 64 to 97.6% and 44 to 93.2%. Only five studies reported a 20-year survival rate, ranging from 46 to 85.1% [6, 15, 19, 46, 48]. Table 3 lists the survival rates obtained with the lateral closing and medial opening wedge technique. The 15-year results were better in the lateral closing wedge group, but data for this length of follow-up were only available in two studies on the medial opening wedge technique.

The survival rates of the studies with and those without Kaplan–Meier survival analysis are presented

Table 2 Risk of bias analysis (ROBINS-I tool)

Article	Bias due to confounding	Bias in selection of participants	Bias in classification of interventions	Bias due to deviation from intended interventions	Bias due to missing data	Bias in measurement of outcome	Bias in selection of reported result
Berruto et al. [6]	Moderate	Moderate	Low	Low	Critical	Low to moderate	Moderate
Song et al. [46]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Kuwashima et al. [30]	Moderate	Moderate	Low	Low	Serious	Low to moderate	Low
Schuster et al. [43]	Moderate	Moderate	Low	Low	Low	Low to moderate	Low
van Wulfften Palthe et al. [52]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Duivenvoorden et al. [15]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Moderate
Niinimäki et al. [35]	Moderate	Low	Moderate to serious	Low	Moderate	Low	Low
Efe et al. [16]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Schallberger et al. [42]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Saragaglia et al. [41]	Moderate	Moderate	Low	Low	Low	Low to moderate	Low
Hui et al. [26]	Moderate	Serious	Low	Low	Moderate	Low to moderate	Low
van Raaij et al. [51]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Akizuki et al. [1]	Moderate	Moderate to serious	Low	Low	Moderate	Low to moderate	Low
Gstöttner et al. [20]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Papachristou et al. [38]	Moderate	Moderate	Low	Low	Serious	Low to moderate	Low
Flecher et al. [19]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Trieb et al. [50]	Moderate	Serious	Low	Low	Moderate	Low	Moderate
Huang et al. [25]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Koshino et al. [29]	Moderate	Moderate	Low	Low	Critical	Low to moderate	Low
Sprenger et al. [48]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Flamme et al. [18]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Hernigou et al. [22]	Moderate	Moderate	Low	Low	Moderate	Low	Low
Hantes et al. [21]	Moderate	Moderate	Low	Low	Low	Moderate	Low
Polat et al. [40]	Moderate	Moderate	Low	Low	Moderate	Low to moderate	Low
Benzakour et al. [4]	Moderate	Moderate to serious	Low	Low	No Information	Moderate	Low
Hernigou et al. [24]	Moderate	Moderate	Low	Low	Low	Serious	Low
Omori et al. [36]	Moderate	Moderate to serious	Low	Low	Moderate	Moderate	Low

Table 2 (continued)

Article	Bias due to confounding	Bias in selection of participants	Bias in classification of interventions	Bias due to deviation from intended interventions	Bias due to missing data	Bias in measurement of outcome	Bias in selection of reported result
Pfahler et al. [39]	Moderate	Moderate	Low	Low	Moderate	Moderate	Low
Choi et al. [9]	Moderate	Moderate to serious	Low	Low	Critical	Moderate	Low
Majima et al. [32]	Moderate	Moderate to serious	Low	Low	Serious	Moderate	Low

Table 3 Summary of high tibial osteotomy survival rates

Survival rate	Lateral closing wedge	Medial opening wedge
5-Year	86–100%	88.6–96.1%
10-Year	70–97.6%	64–90%
15-Year	44–93.2%	45–68%
20-Year	46–85.1%	No information

in Tables 4, 5, respectively. These tables also contain information about the age of the patients at the time of surgery, ranging from 15 to 84 years.

Comparing the survival rate of subgroups was not possible given the large variety of characteristics between the articles, as illustrated by Tables 6, 7.

2. Functional scores, patient satisfaction and pain scores

Several studies presented functional scores and/or information on patient satisfaction and pain levels preoperatively and at final follow-up. Many different functional scores were used in the articles, which made it difficult to compare the obtained results. However, all these scoring systems showed higher results, maintained until final follow-up, compared to preoperatively. Nine articles added a significance level to the change in functional scores and the improvement was significant in all of them [6, 9, 18, 21, 29, 32, 36, 39, 43].

Twelve articles, representing a total of 1456 patients, separately mentioned the effect of the procedure on the satisfaction level [6, 9, 18, 19, 25, 26, 29, 38, 39, 41, 42, 48]. According to these studies, between 77 and 98% of patients were (very) satisfied after a mean follow-up of more than 10 years. Hui et al. showed that 68% of the subgroup who had to undergo a revision to arthroplasty was still satisfied [26]. The mean onset for dissatisfaction was 10.7 years in the study by Huang et al. and 14.2 years in the study by Flecher et al. [19, 25].

Four articles, representing a total of 308 patients, described a sustained improvement of the patient's pain level at final follow-up, compared to preoperatively [6, 20, 38, 39].

Secondary outcome measures

1. Alignment correction

The terms 'femorotibial alignment' and 'anatomical tibiofemoral axis' refer to the angle between the anatomical axis of the shaft of the femur and the tibia, which is approximately 5°–7° of valgus in healthy knees [37].

The terms 'mechanical tibiofemoral axis' and 'hip–knee angle' refer to the angle between the mechanical axis of the femur and the tibia, which is approximately 1° (±3°) of varus in healthy knees [10].

In the studies using the mean femorotibial alignment or anatomical tibiofemoral axis, this angle ranged from 0.1° valgus to 9.6° varus preoperatively and was corrected to a mean of 7.3°–13.8° valgus postoperatively [1, 9, 18, 19, 25, 26, 29, 30, 32, 36, 39, 42, 46, 52]. The goal of most of these studies was to correct the alignment to a valgus angle of 8°–10° [9, 18, 25, 26, 29, 39].

In the studies using the mean mechanical tibiofemoral axis or hip–knee angle, this angle ranged from 5.8° to 18° varus preoperatively and was corrected to a mean of 0.6°–4° valgus postoperatively [4, 6, 15, 16, 20, 21, 24, 41, 43, 46, 51]. The aim of most of these studies was to correct the alignment to a valgus angle of 3°–6° [4, 22, 24, 41, 51].

Eight articles expressed the desired degree of overcorrection in a different way [1, 19, 21, 30, 32, 36, 40, 46]. The purpose in four of those articles was to redirect the alignment axis through the middle of the lateral tibial plateau [1, 30, 32, 36]. The other four articles wanted the alignment axis to pass through Fujisawa point, located at 62% of the tibial plateau width when measured from the medial side [19, 21, 40, 46].

2. Factors influencing survival

The 21 articles that evaluated the impact of potential risk factors on the survival rate of high tibial osteotomies provided contradictory results. Table 8 presents the findings from the articles investigating commonly

Table 4 Summary of results from articles with Kaplan–Meier survival analysis

References	Publication year (time fork HTO)	Number of patients (number of knees)	Type of HTO	Mean age at time of surgery in years ± SD (range)	5-Year survival rate	10-Year survival rate	15-Year survival rate	17-Year survival rate	18-Year survival rate	20-Year survival rate
Berruto et al. [6]	2020 (1989–2012)	82 Patients (94 knees)	C	55.3 (45–73)		92%	82%			80%
Song et al. [46]	2019 (1993–1998)	60 Patients (60 knees)	C	59.7 (55–65)	100%	91%	63.4%			48.3%
Kuwashima et al. [30]	2019 (1991–2011)	158 Patients (202 knees)	C	61.4 (40–82)	99.1%	94.4%	84.6%			
Schuster et al. [43]	2018 (2005–2008)	73 Patients (79 knees)	O	50.9 (29–67)	96.1%	81.7%				
van Wulfften Palthe et al. [52]	2018 (1992–2002)	49 Patients (35 C,14 O)	C vs O	54 (24–80)		77% (C) 64% (O)	44% (C) 45% (O)			
Duivenvoorden et al. [15]	2017 (1993–2012)	412 Patients (354 C,112 O)	C vs O	49.2 ± 9.3		75% (C) 90% (O)				50% (C)
Niinimäki et al. [35]	2012 (1987–2008)	3195 Patients (3195 knees)	C and O	54 (18–84)	89%	73%				
Efe et al. [16]	2011 (1984–2001)	199 Patients (199 knees)	C	54 ± 8	93%	84%	68%			
Schallberger et al. [42]	2011 (1984–1992)	54 Patients (55 knees)	C and O	40 (15–68)	98%	92%	71%			
Saragaglia et al. [41]	2011 (1995–2000)	110 Patients (124 knees)	O	53.2 (32–74)	88.6%	74%				
Hui et al. [26]	2010 (1990–2001)	455 Patients (455 knees)	C	50 (24–70)	95%	79%	56%			
van Raaij et al. [51]	2008 (1991–1996)	100 Patients (100 knees)	C	49 (24–67)		75%				
Akizuki et al. [1]	2008 (1987–1996)	94 Patients (118 knees)	C	62.9 (45–76)	99.3%	97.6%	90.4%			
Gstöttner et al. [20]	2008 (1981–1997)	111 Patients (134 knees)	C	54.5 (19–74)	94%	79.9%	65.5%		54.1%	
Papachristou et al. [38]	2006 (1981–1996)	42 Patients (44 knees)	C	51 (26–60)		80%	66%	52.5%		
Flecher et al. [19]	2006 (1975–1990)	313 Patients (372 knees)	C	42 (15–76)	94.8%	92.8%	89.7%			85.1%
Trieb et al. [50]	2006 (?)	63 Patients (94 knees)	C	59.8 (42–76)		90% (< 65 year) 70% (> 65 year)				
Huang et al. [25]	2005 (1984–1994)	82 Patients (93 knees)	C	57.4 (38–73)	94.6%	87%	75.2%			
Koshino et al. [29]	2004 (1970–1985)	53 Patients (75 knees)	C	59.6 (46–73)	97.8%	96.2%	93.2%			

Table 4 (continued)

References	Publication year (time fork HTO)	Number of patients (number of knees)	Type of HTO	Mean age at time of surgery in years ± SD (range)	5-Year survival rate	10-Year survival rate	15-Year survival rate	17-Year survival rate	18-Year survival rate	20-Year survival rate
Sprenger et al. [48]	2003 (1972–1990)	66 Patients (76 knees)	C	69 (47–81)	86%	73.9%	56%			46%
Flamme et al. [18]	2003 (1989–1992)	100 Patients (112 knees)	C	58 (19–79)		81%				
Hernigou et al. [22]	2001 (1985–1994)	197 Patients (245 knees)	O	60 (35–73)	94%	85%	68%			

HTO high tibial osteotomy, *SD* standard deviation, *O* opening wedge high tibial osteotomy, *C* closing wedge high tibial osteotomy

addressed risk factors [1, 6, 9, 16, 19, 20, 24–26, 29, 30, 35, 36, 38, 39, 41, 43, 48, 50–52]. In the studies that identified an influence of these risk factors, older age, female gender, higher BMI, higher preoperative degrees of osteoarthritis, larger preoperative varus angles and undercorrection of the alignment resulted in worse outcomes.

Table 9 shows the results from the seven articles that analyzed some other potential risk factors [1, 6, 9, 16, 26, 39, 43]. In the studies that found an impact of these additional risk factors, a lesser preoperative knee function, a history of knee surgery and a postoperative increase of osteoarthritis in the lateral knee compartment resulted in a worse outcome, whereas the absence of an anterior cruciate ligament led to better results.

Discussion

The most important findings of this systematic review were the good to excellent long-term survival rates and patient-reported outcomes obtained with the lateral closing and medial opening wedge high tibial osteotomy. The contribution of the Finnish registry-based study by Niinimäki et al. is noteworthy given its large sample size (3195 knees) and its study design that included patients from both state-funded and private hospitals [35]. They obtained a 5-year and 10-year survival rate of, respectively, 89% and 73%. Most other articles portrayed better results. A possible explanation for this difference could be the introduction of a bias in the other studies by only presenting results from very experienced professionals. Niinimäki et al. conducted their study to establish such a discrepancy [35]. A prior Swedish population-based study corroborates this statement by showing a 10-year survival rate of 70%, which is similar to the Finnish study [53].

Three included studies (reporting on the lateral closing wedge technique) had remarkably better results than the other ones after 5, 10 and 15 years and the difference became more noticeable with increasing length of follow-up [1, 19, 29]. These articles demonstrated the possibility to maintain excellent results for longer than 15 years. However, these results should be interpreted with caution given the low quality of the studies included in this systematic review.

It remains unclear whether the lateral closing wedge and medial opening wedge technique are equivalent alternatives [2, 45]. Wang et al. conducted a meta-analysis of nine studies with short- to medium-term follow-up to answer this question, but they could not conclude which technique is superior [54]. In this systematic review, the results of the lateral closing wedge technique were slightly better than those

Table 5 Summary of results from articles without Kaplan–Meier survival analysis

References	Publication year (time fork HTO)	Number of patients (number of knees)	Type of HTO	Mean age at time of surgery in years (range)	10-Year survival rate	12-Year survival rate	14-Year survival rate	15-Year survival rate	17-Year survival rate
Hantes et al. [21]	2018 (2001–2005)	20 Patients (20 knees)	O	35.4 (28–44)		95%			
Polat et al. [40]	2017 (1990–2010)	117 Patients (29 C, 88 O)	C vs O	44.9 (22–68)		86.4% (O)	82.8% (C)		
Benzakour et al. [4]	2010 (1982–2008)	192 Patients (224 knees)	C and O	55 (40–72)				87.9%	
Hernigou et al. [24]	2010 (1997–2001)	41 Patients (53 knees)	O	60 (43–67)	88.7%				
Omori et al. [36]	2008 (1980–1990)	55 Patients (68 knees)	C	59 (40–69)					94.1%
Pfahler et al. [39]	2003 (1985–1993)	73 Patients (86 knees)	C	54 (20–67)	72%				
Choi et al. [9]	2001 (1976–1990)	26 Patients (30 knees)	C	59 (48–70)				87%	
Majima et al. [32]	2000 (1975–1980)	44 Patients (48 knees)	C	59.5 (47–70)		92.9%			

HTO high tibial osteotomy, *O* opening wedge high tibial osteotomy, *C* closing wedge high tibial osteotomy

of the medial opening wedge technique after 10 years. The results after 15 years of follow-up were also better in this group. However, drawing a definite conclusion remains difficult as information for this length of follow-up was only available in two articles on the medial opening wedge technique, presenting the results of 259 osteotomies.

The sole use of the survival rate to assess the outcome of high tibial osteotomies has been criticized in the past as the absence of conversion to arthroplasty does not necessarily equal a good result [15, 41]. Patients can be hesitant to undergo another operation, regardless of the persistence or recurrence of pain and doctors may be less inclined to perform an arthroplasty in younger patients [15, 35, 51]. However, several authors argued that this remains the most objective and valid outcome measure as delaying the need for arthroplasty is the main goal of performing a high tibial osteotomy [19, 51]. Functional scores and questionnaires about patient satisfaction and pain level changes are more subjective evaluation methods. In their review, Webb et al. concluded that good functional scores can be obtained with high tibial osteotomies after short- to medium-term follow-up [55]. This review evaluated the change in functional scores after a mean follow-up of more than 10 years. The studies that presented functional scores showed a considerable improvement postoperatively in most patients, which was maintained until final follow-up. Given that the natural course of osteoarthritis would result in a progressive deterioration of the joint quality and, therefore, also of the functional scores, one could assume that a high tibial osteotomy has a positive and long-lasting impact on the functional outcome [17].

The optimal correction angle has been a point of discussion since high tibial osteotomies were initially introduced. The general consensus is that an overcorrection to valgus alignment produces the best results, but the exact amount of correction remains debatable. An insufficient correction can result in the gradual recurrence of varus alignment [12, 23]. In the past, some authors insisted on performing large overcorrections [27, 48]. Others advised against it as it is cosmetically unpleasing and can lead to a faster progression of osteoarthritis in the lateral compartment [12, 23]. Therefore, surgeons, nowadays, mostly aim for a moderate overcorrection of the anatomical tibiofemoral axis to 8–10° of valgus or of the mechanical tibiofemoral axis to 3–6° of valgus, as was the case in most of the included studies.

In this systematic review, the difference in survival of the osteotomy between the studies became more pronounced with increasing length of follow-up. This could indicate an influence from certain factors that differed between the articles. Identifying these risk factors might make it possible to refine the indications for high tibial osteotomies and achieve even higher survival rates. Many authors already investigated the influence of age, BMI, gender, osteoarthritis grade, preoperative and postoperative alignment extensively in the past [5, 12, 27, 34, 47]. Their results were often contradictory, as was the case in this systematic review. One of the possible explanations for this discord might be the lack of extremes in certain studies. Huang et al. could not

Table 6 Additional information from the studies with Kaplan–Meier survival analysis

References	Alignment goal	Mean preoperative alignment ± SD	Mean postoperative alignment ± SD	Mean alignment at final follow-up ± SD	Filling material of gap (OWHTO)	Fixation method of osteotomy	Postoperative rehabilitation protocol
Berruto et al. [6]	0°–3° varus (HKA)	6.9° varus ± 2.3° (HKA)	/	2.6° varus ± 1.6° (HKA)	/	Two staples	Partial weightbearing (brace, 20 kg) for 45 days with stretching and quadriceps exercises
Song et al. [46]	Fujisawa point	10.3° varus ± 3.3° (mTFA) or 2.5° varus ± 5.1° (FTA)	1.7° valgus ± 2.7° (mTFA) or 7.9° valgus ± 3.2° (FTA)	4.1° varus ± 6.5° (mTFA) or 2.4° valgus ± 5.8° (FTA)	/	Miniplate staple	Passive range of motion exercises after 2 days Straight-leg-raising exercises after 3 days Partial weightbearing after 4–5 days Full weightbearing after 6 weeks
Kuwashima et al. [30]	Middle of lateral compartment	0.1° valgus ± 3.8° (FTA)	11.9° valgus ± 3.0° (FTA)	/	/	Staple or locking plate	Full weightbearing after 6–8 weeks
Schuster et al. [43]	0°–3° valgus (mTFA)	9.6° varus ± 3° (mTFA)	0.6° valgus ± 2.7° (mTFA)	/	No filling (autologous iliac crest bone in 4 cases)	Angular-stable Tomofix implant	Partial weightbearing (10–20 kg) for 8 weeks with passive range of motion exercises
van Wulfften Palthe et al. [52]	/	1.4° varus ± 3.3° (FTA)	7.3° ± 4.0° (FTA)	/	/	Compression plate	Full weightbearing allowed immediately
					Calcium phosphate	Locking plate	Full weightbearing allowed immediately
Duivenvoorden et al. [15]	/	6.6° varus ± 2.6° (HKA)	/	/	/	Two staples or Tomofix plate or Puddu plate	No information
					No filling (autologous iliac crest bone for large wedges)	Tomofix plate or Puddu plate	No information
Niinimäki et al. [35]	/	/	/	/	No information	No information	No information
Efe et al. [16]	/	6.0° varus ± 3.0° (HKA)	/	/	/	AO plate	Early active movement and physiotherapy Partial weightbearing (2 crutches) for 6 weeks

Table 6 (continued)

References	Alignment goal	Mean preoperative alignment ± SD	Mean postoperative alignment ± SD	Mean alignment at final follow-up ± SD	Filling material of gap (OWHTO)	Fixation method of osteotomy	Postoperative rehabilitation protocol
Schallberger et al. [42]	/	2.0° varus (aTFA)	10.0° valgus (aTFA)	8.0° valgus (aTFA)	/	Bent one-half tubular plate and two screws	Partial weightbearing (splint, 15 kg) with full motion for 6–8 weeks
					Iliac crest (autologous)	Plate	Partial weightbearing (splint, 15 kg) with full motion for 6–8 weeks
Saragaglia et al. [41]	4° valgus (HKA)	7.5° varus ± 3.8° (HKA)	2.0° valgus ± 1.8° (HKA)	/	Beta tricalcium phosphate	AO T-shaped plate and screws	Full weightbearing on average after 60 days
Hui et al. [26]	10° valgus (FTA)	0° varus ± 3.8° (FTA)	10.3° valgus ± 1.9° (FTA)	/	/	Krakow staple	Cast (from 1990–1996) Brace (from 1997) Full weightbearing after 6 weeks
van Raaij et al. [51]	4° valgus (HKA)	6.5° varus ± 3.7° (HKA)	/	/	/	Two step staples	Cast and partial weightbearing (2 crutches) for 6 weeks
Akizuki et al. [1]	Middle of lateral compartment	3.7° varus ± 4.5 (FTA)	13.8° valgus ± 4.7° (FTA)	13.0° valgus ± 6.9° (FTA)	/	Giebel plate	Immediate active movement and physiotherapy Partial weightbearing (crutches) for 6 weeks
Gstöttner et al. [20]	/	/	3.4° valgus (mTFA)	/	/	Staple	Partial weightbearing (knee brace and crutches) for 6 weeks
Papachristou et al. [38]	/	2.3° varus ± 0.6° (?)	5.8° valgus ± 0.5° (?)	2.6° valgus ± 0.5° (?)	/	One or two staples	Immediate strengthening exercises and partial weightbearing (crutches) Full weightbearing after a mean time of 7 weeks
Flecher et al. [19]	Between tibial spine and center lateral compartment	6.0° varus (FTA)	/	4.0° valgus ± 1.9° (FTA)	/	Blount staple and AO half-tube plate with three screws	Immediate full motion and partial weightbearing (crutches) for 45 days
Trieb et al. [50]	/	/	/	/	/	Staples with screw in distal part	Cast for 6 (4–10) weeks

Table 6 (continued)

References	Alignment goal	Mean preoperative alignment ± SD	Mean postoperative alignment ± SD	Mean alignment at final follow-up ± SD	Filling material of gap (OWHTO)	Fixation method of osteotomy	Postoperative rehabilitation protocol
Huang et al. [25]	8°–10° valgus (FTA)	5.3° varus (FTA)	/	8.5° valgus (FTA)	/	Two staples	Cast and non-weightbearing for 4 weeks Active movement and partial weightbearing (toe-touch) after 4 weeks Full weightbearing after 3 months
Koshino et al. [29]	10° valgus (aTFA)	6.0° varus ± 6.5° (aTFA)	/	9.0° valgus ± 7.5° (aTFA)	/	Blade plate or external fixation clamps or dual plating	Cast was applied to 16 legs
Sprenger et al. [48]	/	/	/	/	/	Screws with figure-of-eight wire and AO plate	Partial weightbearing (toe-touch) after 6 weeks Full weightbearing after 12 weeks
Flamme et al. [18]	8°–9° valgus (aTFA)	9.6° varus (aTFA)	/	/	/	5-hole-one-third tubular plate and screw	Partial weightbearing (10 kg) for 10 weeks Then increase of 10 kg per week
Hernigou et al. [22]	3°–6° valgus (HKA)	/	/	/	Bone cement	Plate and screws	Immediate static and dynamic exercises Weightbearing on average after 45 days

SD standard deviation, *OWHTO* opening wedge high tibial osteotomy, *HKA* hip–knee angle, *mTFA* mechanical tibiofemoral angle, *FTA* femorotibial angle, *aTFA* anatomical tibiofemoral angle

Table 7 Additional information from the studies without Kaplan–Meier survival analysis

References	Alignment goal	Mean preoperative alignment ± SD	Mean postoperative alignment ± SD	Mean alignment at final follow-up ± SD	Filling material of gap (OWHTO)	Fixation method of osteotomy	Postoperative rehabilitation protocol
Hantes et al. [21]	Fujisawa point	5.8° varus ± 2.4° (mTFA)	2.5° valgus ± 1.9° (mTFA)	2.2° valgus ± 1.7° (mTFA)	No filling	Tomofix plate	Partial weightbearing (20 kg) for 6 weeks
Polat et al. [40]	Fujisawa point	/	/	/	/	Two or three offset staples	Partial weightbearing (brace and two crutches) for 6 weeks Full weightbearing and strengthening exercises after 6 weeks
					Autogenic or allogenic bone graft	Puddu plate	Partial weightbearing (brace and two crutches) for 6 weeks Full weightbearing and strengthening exercises after 6 weeks
Benzakour et al. [4]	5° valgus (mTFA)	11° varus (mTFA)	/	4° valgus (mTFA)	/	Buttress plate or staples	Progressive weightbearing from 3 to 6 weeks and active exercises
		13° varus (mTFA)	/	2° valgus (mTFA)	Synthetic graft or autologous iliac bone	Buttress plate or staples	Cast at the beginning of the study
Hernigou et al. [24]	3°-6° valgus (HKA)	18° varus (HKA)	4° valgus (HKA)	0° valgus (HKA)	Tricalcium phosphate	Buttress plate	Immediate passive motion and quadriceps exercises Full weightbearing after 45 days
Omori et al. [36]	Middle lateral compartment	5.4° varus ± 4.4° (FTA)	11.8° valgus ± 2.9° (FTA)	10.2° valgus ± 5.2° (FTA)	/	Two threaded pins and figure-of-eight wire	Cast immobilization for 6 weeks Partial weightbearing after 4 weeks Full weightbearing after 8–10 weeks
Pfahler et al. [39]	/	1.4° varus (aTFA)	9.6° valgus (aTFA)	6.8° valgus (aTFA)	/	No information	No information
Choi et al. [9]	10° valgus (FTA)	6.9° varus ± 2.0° (FTA)	10.0° valgus ± 2.5° (FTA)	5.9° valgus ± 5.8° (FTA)	/	Koshino plate and screws or staples or K-wires	Cast for 4 weeks Partial weightbearing (2 crutches) after 14 days

Table 7 (continued)

References	Alignment goal	Mean preoperative alignment ± SD	Mean postoperative alignment ± SD	Mean alignment at final follow-up ± SD	Filling material of gap (OWHTO)	Fixation method of osteotomy	Postoperative rehabilitation protocol
Majima et al. [32]	Middle lateral compartment	5.1° varus ± 6.3° (FTA)	/	9.0° valgus ± 6.1° (FTA)	/	Two Steinmann pins and external fixation	Active movement after 1 day Partial weightbearing after 6 weeks Full weightbearing after 8 weeks

SD standard deviation, *OWHTO* opening wedge high tibial osteotomy, *HKA* hip–knee angle, *mTFA* mechanical tibiofemoral angle, *FTA* femorotibial angle, *aTFA* anatomical tibiofemoral angle

identify the preoperative grade of osteoarthritis as risk factor, but they only included patients with mild changes [25]. The same goes for the studies by Van Raaij et al. and Flecher et al. with respect to the effect of the preoperative alignment [19, 51].

Age at the time of surgery may only have had an influence in certain studies because surgeons were less inclined to perform a conversion to arthroplasty in younger patients [35, 51].

A strength of this systematic review is the large sample size through the inclusion of thirty articles, presenting results from 7087 high tibial osteotomies in a total of 6636 patients after a mean follow-up of more than 10 years. Another strength is the availability of results after more than 15 years of follow-up in nineteen studies, examining the results of a total of 2700 patients.

This is the first study that systematically presents the long-term results of high tibial osteotomies in that many patients after a mean follow-up of more than 10 years.

The main limitation of this systematic review is the low quality of the included articles. Almost all are retrospective studies without a control group and the follow-up rate is low in some articles. Another weakness is the pronounced lack of uniformity between the included studies and their contradictory results regarding the influence of potential risk factors. These major limitations somewhat impede drawing definite conclusions about the position of high tibial osteotomies in current practice and emphasize the need for prospective studies of higher quality in the future. However, the results of this systematic review are encouraging and suggest that the lateral closing and medial opening wedge high tibial osteotomy remain valid treatment options for patients with isolated medial compartment osteoarthritis of the knee.

Conclusion

Despite the low quality of the available evidence, the lateral closing and medial opening wedge high tibial osteotomy seem to remain valid long-term treatment options for patients with painful varus malalignment caused by isolated medial compartment osteoarthritis of the knee. This is demonstrated by the good to excellent long-term survival rates and functional scores obtained in this systematic review. The ideal candidate appears to be a non-obese male who is less than 65 (and preferably even less than 50) years old, with a low grade of medial osteoarthritis and a limited preoperative varus angle. However, good results still seem to be achievable in patients with some potential risk factors for failure [24, 26, 36, 43]. The results of this systematic review indicate that the need for arthroplasty could be delayed for more than 15 years in the majority of patients, but higher-quality studies are needed to confirm these findings.

Table 8 Identification of potential risk factors for high tibial osteotomy survival

Risk factor	Age	Gender	BMI	Osteoarthritis grade	Preoperative alignment	Postoperative alignment
Yes	(1) Saragaglia et al. [41] (2) Hui et al. [26] (3) Gstöttner et al. [20] (4) Flecher et al. [19] (5) Trieb et al. [50] (6) Pfahler et al. [39] (7) van Wulfften Palthe et al. [52] (8) Niinimäki et al. [35] (9) Berruto et al. [6]	(1) van Raaij et al. [51] (2) Sprenger et al. [48] (3) van Wulfften Palthe et al. [52] (4) Niinimäki et al. [35] (5) Berruto et al. [6]	(1) Hui et al. [26] (2) Akizuki et al. [1] (3) Flecher et al. [19] (4) Pfahler et al. [39]	(1) Efe et al. [16] (2) van Raaij et al. [51] (3) Flecher et al. [19]	(1) Huang et al. [25]	(1) Schuster et al. [43] (2) Saragaglia et al. [41] (3) Hernigou et al. [24] (4) Omori et al. [36] (5) Flecher et al. [19] (6) Papachristou et al. [38] (7) Koshino et al. [29] (8) Pfahler et al. [39] (9) Sprenger et al. [48] (10) Choi et al. [9] (11) Berruto et al. [6]
No	(1) Schuster et al. [43] (2) Efe et al. [16] (3) Akizuki et al. [1] (4) van Raaij et al. [51] (5) Huang et al. [25] (6) Sprenger et al. [48] (7) Kuwashima et al. [30]	(1) Schuster et al. [43] (2) Hui et al. [26] (3) Efe et al. [16] (4) Akizuki et al. [1] (5) Gstöttner et al. [20] (6) Flecher et al. [19] (7) Huang et al. [25]	(1) Efe et al. [16] (2) van Raaij et al. [51] (3) Huang et al. [25] (4) Sprenger et al. [48] (5) van Wulfften Palthe et al. [52] (6) Berruto et al. [6]	(1) Saragaglia et al. [41] (2) Akizuki et al. [1] (3) Omori et al. [36] (4) Huang et al. [25] (5) Sprenger et al. [48]	(1) Efe et al. [16] (2) Akizuki et al. [1] (3) van Raaij et al. [51] (4) Gstöttner et al. [20] (5) Flecher et al. [19] (6) van Wulfften Palthe et al. [52]	(1) Akizuki et al. [1] (2) Gstöttner et al. [20] (3) Huang et al. [25] (4) van Wulfften Palthe et al. [52]

Yes = an influence was established, No = no influence was established

Table 9 Identification of other potential risk factors for high tibial osteotomy survival

Risk factor	Preoperative knee function	Knee operation in history	Osteoarthritis grade lateral compartment	ACL status	MCL laxity	Osteoarthritis cause	Smoking
Yes	Schuster et al. [43]	Pfahler et al. [39]	Pfahler et al. [39]	Hui et al. [26]	/	/	/
No	Akizuki et al. [1]	(1) Hui et al. [26] (2) Efe et al. [16]	Choi et al. [9]	/	Hui et al. [26]	Hui et al. [26]	Berruto et al. [6]

Yes = an influence was established, No = no influence was established

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