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Review

A systematic review of outcomes of high tibial osteotomy for the valgus knee

Alannah Coakley [a], Michael McNicholas [b,c], Leela Biant [b,d,e], Gwenllian Tawy [b,*]

[a] Division of Medical Education, School of Medical Sciences, The University of Manchester, Manchester UK
[b] Division of Cell Matrix Biology & Regenerative Medicine, School of Biological Sciences, The University of Manchester, Manchester, UK
[c] Department of Orthopaedics, Aintree University Hospital, Liverpool University HOspitals NHS Foundation Trust, Liverpool, UK
[d] Department of Orthopaedics, Trafford General Hospital, Manchester University NHS Foundation Trust, Manchester, UK
[e] Centre of Health Sciences Research, University of Salford, Manchester, UK

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ABSTRACT

Purpose: Osteoarthritis is a prolific condition in an increasingly ageing and obese population. Research into treatments of this condition and their efficacy are vital. Outcomes of high tibial osteotomy (HTO) for the varus knee is widely reported. There is less evidence for HTO in the valgus knee.

This systematic review aimed to compile all literature reporting the outcomes of HTO to correct the valgus knee, focusing on post-operative clinical outcomes.

Methods: Ovid MEDLINE, Embase and Web of Science were searched using key terms: Osteoarthritis [All Fields] AND High tibial osteotomy [All Fields] AND Lateral OR Valgus [All Fields]. Papers were screened for eligibility based on an inclusion and exclusion criteria. Full text screening was completed by two reviewers and data was extracted from the agreed included papers by one reviewer. Quality assessments of the papers were also conducted. PROSPERO ID: CRD42021239045.

Results: Across 17 papers reporting 517 knees, the average pre-operative femorotibial and hip-knee-ankle angles were corrected from 13.6 ± 7.0° and 4.9 ± 1.9° valgus to 2.8 ± 2.9° and 1.2 ± 1.7° varus. Studies show that the procedure is successful at offloading the lateral knee compartment and some evidence it can delay the need for a total knee replacement. However, its impact on overall quality of life remains poorly understood.

Conclusions: High tibial osteotomy may be a viable treatment option for valgus knee deformities caused by lateral compartment osteoarthritis. Nevertheless, research into the procedure remains limited. Importantly, our understanding of the relationship between the achieved alignment and outcome remains largely unknown.

Level of evidence: IV.

Abbreviations: HTO, High tibial osteotomy; OA, Osteoarthritis; DFO, Distal femoral osteotomy; BMI, Body mass index; HKA, Hip-knee-ankle angle; FTA, Femorotibial angle; KOOS, Knee Osteoarthritis Outcome Score; PROM, Patient reported outcome measure.

* Corresponding author at: 1.541 Stopford Building, University of Manchester, Oxford Road, Manchester M13 9PG, UK.
E-mail addresses: gwenllian.tawy@manchester.ac.uk, Gwenllian.Tawy@mft.nhs.uk (G. Tawy).

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Contents

1. Introduction

The knee joint is the most common site of osteoarthritis (OA) in adults over the age of 45 in the UK, with a global prevalence of 22.9 % [1,2]. Conservative treatment options for patients with knee OA include lifestyle changes and pharmacological pain management [3]. When conservative treatments cease to be effective at treating the symptoms of OA, surgical treatments are considered. The selection of surgical intervention is dependent on the indications of the procedure and specific patient criteria. In younger and more active patients with unicompartmental OA, high tibial osteotomy (HTO) is often considered a suitable treatment option [4–6].

HTO aims to alter the alignment of the knee joint to redistribute the weight load across the joint and off-load worn compartments. This not only relieves pain and improves mobility in patients but can also prevent the need for full or partial joint replacement by up to 10 years [4–6]. Current research indicates HTO specifically in patients with isolated medial compartment OA and varus deformities [7–9].

Unicompartmental OA is less common in the lateral compartment of the knee than in the medial compartment. As a result, the literature on the outcomes and efficacy of surgical procedures to treat OA usually exclude patients presenting with genu valgum.

Distal femoral osteotomy (DFO) is typically the treatment option for lateral compartment OA, especially when the valgus deformity exceed 12° [7,10,11]. However, several studies have investigated the efficacy of HTO to treat lateral OA, and the procedure is commonly used as an alternative [7,12–18]. Previously, authors have discussed the importance of osteotomies taking place at the location of the deformity, indicating the requirement of a tibiofemoral joint deformity of this nature to be treated at the tibia and not superior to the femoral condyles [19,20]. Furthermore, evidence suggests that HTO is potentially more beneficial for the more active patient [21].

Given the increasing use of HTO to treat unicompartmental OA, it is becoming more important for clinicians and patients to understand it's efficacy as a treatment for lateral knee OA [11,22]. The aim of this systematic review was to investigate the outcome of HTO that corrects the valgus knee.

2. Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement. The protocol of this review was pre-determined and is registered on PROSPERO [ID: CRD42021239045; https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021239045].

2.1. Search strategy

Systematic searches of the literature using limited keywords and MeSH terms were conducted using three databases: Ovid MEDLINE, Embase and Web of Science. The individual resource parameters for the searches were: Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Daily and Versions(R) 1946 to March 2, 2021; Embase 1947 to March 2 2021; Web of Science All Years 1900 to March 2 2021. An updated search with the same parameters restricted to publications between 2021 and 2022 was completed after the original search to identify any new publications for review. An additional search of the PROSPERO database was conducted to search for any ongoing or unpublished systematic reviews on the same topic. The search terms that were used to select the literature were: Osteoarthritis [All Fields] AND High tibial osteotomy [All Fields] AND Lateral OR Valgus [All Fields]. The references of eligible articles were also searched manually for additional eligible articles.

2.2. Eligibility

Completed searches were exported from the three databases to a reference manager (EndNote x9 - Clarivate, London, UK). Duplicates of papers were removed using a function in EndNote, or manually where the function did not identify the papers as duplicates. Screening was performed in two stages by two reviewers (reviewers: AC and GT); firstly, screened by title and abstract and then assessed after reading the entire publication. In the instance of a disagreement over eligibility of inclusion, a third-party reviewer (reviewer: LB) was available to resolve this.

The inclusion of studies was based on the fulfillment of the following inclusion criteria:

1. Included patients who have undergone a HTO to treat valgus OA of any severity
2. Included any reported patient outcome measure or biomechanical outcome
3. Written in English language

The exclusion criteria for this systematic review were as follows:

1. Included patients who have undergone a HTO for conditions other than OA
2. Included patients who have undergone a HTO for medial correction (genu varum)
3. Included patient who have undergone a HTO in combination with another procedure
4. Cadaveric studies
5. Animal or cell studies
6. Mathematical/Computational models
7. Finite element or model analysis
8. Did not report any outcomes
9. Reports where data was presented in a way that it could not be extracted from the text

Abstracts, conference presentations, book chapters and case reports were also reviewed under the inclusion criteria.

2.3. Quality assessment

All eligible studies were screened independently for bias by two reviewers (AC and GT). The National Institute of Health Quality Assessment Tool was used to score the quality of the papers and assess risk of bias. Both reviewers graded each paper independently in line with the assessment tool. This criterion is specific in terms of study design and execution. If the two independent scores for a study were within 2 points, an average score was calculated. The average score was used to determine whether the study would be graded as ‘good’, ‘fair’ or ‘poor’. If the two scores for a study were greater than 2 points apart, a third reviewer (LB) was asked to assess the quality of the paper using the same tool. Declared conflicts of interest were also reported for the purpose of this review to assess the risk of bias.

2.4. Data extraction and synthesis

Data exported from the eligible papers included author name, year of publication, type of study, study quality, reported conflict of interest, reported patient demographics (body mass index (BMI), gender ratio, mean age), reported information about the surgical approach and any patient reported outcomes or biomechanical variables. All data were exported into a Microsoft Excel spreadsheet (Microsoft, Albuquerque, United States) by one author (AC) and validated by a second author (GT). Discrepancies were usually resolved between GT and AC, but a third independent reviewer (LB) was available if GT and AC disagreed on the data extracted into the spreadsheet for analysis.

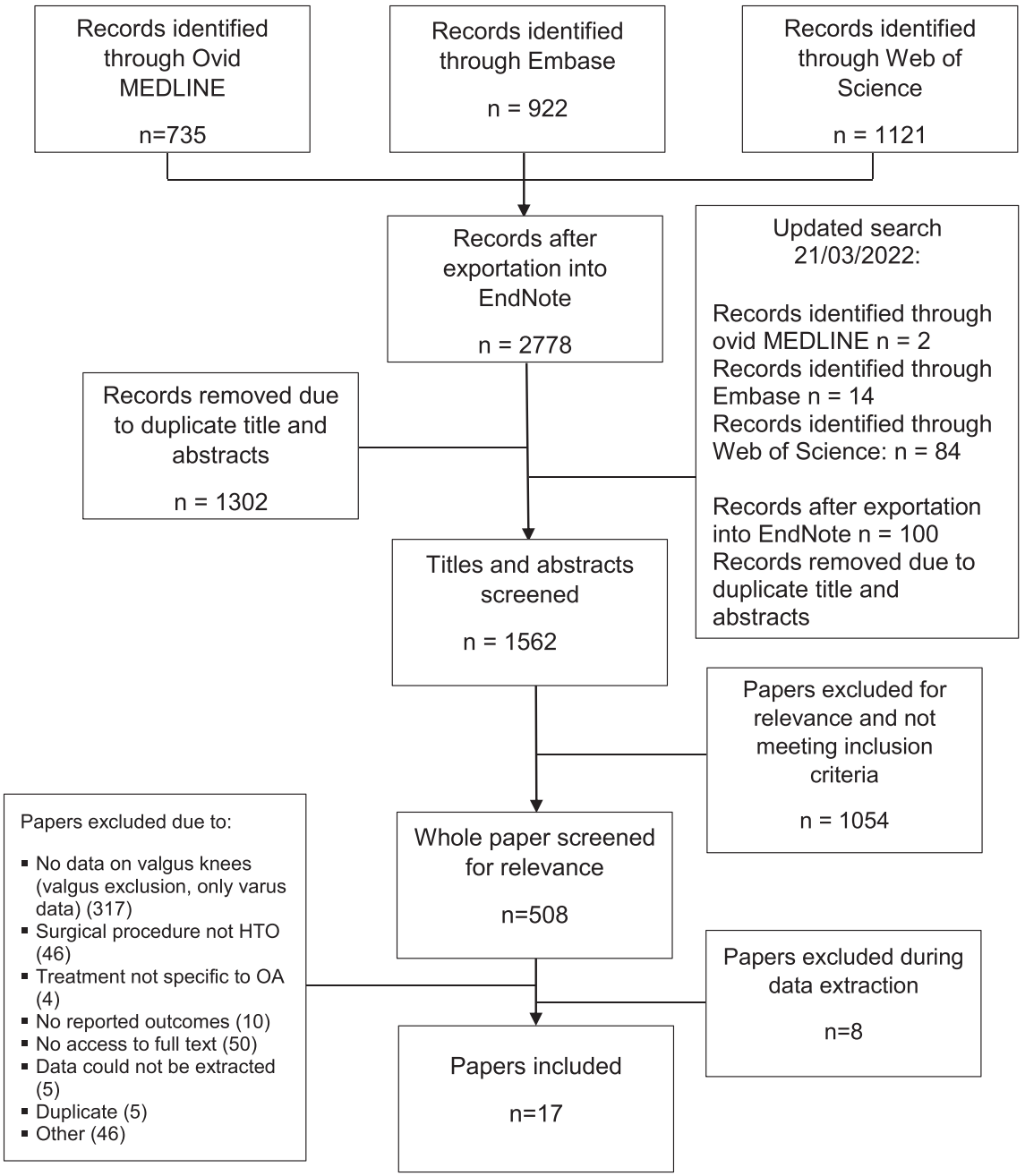

Figure 1. Flowchart displaying method of systematic search.

2.5. Data analysis

All outcomes collected for this study were initially grouped in Microsoft Excel, based on their type. Outcomes were characterized under one of the following groups: 1 - Participant Characteristic (e.g. demographics/surgical information); 2 - Radiographic Outcome (e.g. pre- and post-operative alignments); 3 - Patient Reported Outcome' (e.g. subjective pain score); 4 - Biomechanical Outcome (e.g. objective knee range of motion); 5 - Complication or Success Rate (e.g. number of subsequent total knee replacement operations).

Discreet variables were then identified within each group to collate all outcomes that were the same across all studies. For example, the average ages reported in all papers were defined as one variable of the 'Participant Characteristic' group. Subgrouping the data by variable was essential to be able to determine the mean value of an outcome that was reported

Table 1
Pertinent data about the papers eligible for inclusion in this systematic review.

Author	Year	Type of study	Level of evidence	Study Quality
Baumgarten [12]	2007	Case series	IV	Good
Chambat [21]	2000	Case series	IV	Fair
Collins [13]	2013	Case series	IV	Good
Coventry [7] cited by Hallel [9]	1987 cited in 1995	Case series cited in current opinion	IV	-
Giagounidis [38]	1998	Cohort study	2c	Fair
Hart [39] cited by Hart [40]	2001 cited in 2002	Literature review	V	-
Hoorntje [23]	2019	Case-control study	III	Fair
Jokio [14]	1985	Prospective case series	IV	Good
Marti [15]	2001	Retrospective case series	IV	Good
McCoy [25]	1985	Retrospective case series	IV	Fair
Mirouse [18]	2017	Retrospective case series	IV	Good
Puddu [27]	2007	Literature review	IV	Fair
Shoji [16]	1973	Case series	IV	Good
Surin [26]	1975	Retrospective case series	IV	Fair
Tjornstrand [41]	1981	Retrospective case series	IV	Fair
van Lieshout [17]	2020	Retrospective case series	III	Fair
W-Dahl [24]	2017	Retrospective case series	IV	Good

in multiple papers. This was especially important when reviewing outcomes that can be reported in multiple ways – e.g. knee alignment may be reported as a hip-knee-ankle angle or as the femorotibial angle. Such outcomes were characterized as discreet variables, as they are not equivalent to each other.

Inbuilt functions in Excel were then used to determine the means and standard deviations of all variables identified within each of the 5 groups. The percentages of papers reporting each variable were also calculated in this software and presented in this review.

Where outcomes were only reported in one paper, descriptive statistic of the variables could not be calculated. Instead, the value presented in the paper was simply given as reported and discussed in the context of that paper.

3. Results

3.1. Study selection

The initial searches for this review in 2021 identified 2,778 articles. An updated search conducted in 2022 identified a further 86 articles for review, none of which were identified for inclusion. However, through thorough review of the papers based on the inclusion and exclusion criteria, the final number of papers included in the systematic review was 17 (Figure 1).

Table 2
Patient demographics and surgical data.

Author	**Number of valgus knees**	**Male: Female**	**Average Age**	**BMI (kg/m^2)**	**Average follow up (months)**	**Surgical technique (HTO)**
Baumgarten [12]	6	1:5	39	-	46	Coronal plane
Chambat [21]	47	-	64	-	84	-
Collins [13]	23	12:10	39	26.7	52	Lateral opening wedge
Coventry [7] **cited by Hallel** [9]	23	-	-	-	112.8	-
Giagounidis [38]	31	-	-	-	-	-
Hart [39] **cited by Hart** [40]	18	4:14	41	-	-	Medial closing wedge
Hoorntje [23]	59	12:47	47.1	27.5	42	Medial closing wedge (n = 58)Lateral opening wedge (n = 1)
Jokio [14]	10	-	-	-	24	-
Marti [15]	36	12:22	43	-	132	Lateral opening wedge
McCoy [25]	18	-	59.8	-	57.6	-
Mirouse [18]	19	11:8	54.5	26.1	51.6	Medial closing wedge
Puddu [27]	21	7:14	54		-	Medial Closing Wedge
Shoji [16]	49	3:42	60.2	-	31.5	-
Surin [26]	17	-	-	-	-	
Tjornstrand [41]	18	-	-	-	84	-
van Lieshout [17]	113	35:78	50	27	56	Medial closing wedge
W-Dahl [24]	9	-	-	-	-	Hemicallotasis
Average	**30.4 ± 9**	**11:27**	**50.1 ± 9.0**	**26.8 ± 0.6**	**64.4 ± 32.6**	**N/A**

A number of additional papers were found to report the outcomes of HTO for medial OA and lateral OA; However, as the patient groups were combined, these particular papers were not eligible for inclusion in this review. Of the 17 papers that were included, there were 13 case series (76.5 %), one cohort study (5.9 %), one case control study (5.9 %) and two literature reviews that reported data which was not published elsewhere (11.6 %) (Table 1). The time frame in which these studies were published spans 47 years (1973–2020).

3.2. Study quality

All the papers included in the review were graded 'good' or 'fair'. Marks were typically lost by the description of statistical methods and lack of detail in outcome measures. Conversely, papers consistently scored well in explanation of intervention, definition of study population and the presentation of results. Two papers could not be quality assessed as the original papers where the data was cited could not be accessed.

Three papers declared they had no conflict of interest with regards to the published work [15,17,18]. One disclosed a consultancy with Zimmer Biomet, but it was unclear whether any of the instrumentation used during the study was supplied by this company [23]. None of the other studies provided a conflict of interest statement, making it difficult to assess the risk of bias. Of these, one study disclosed the research was funded by Arthrex, a company who produce Puddu opening wedge osteotomy systems, which were used in the study [13].

Table 3
Radiographic Data from included studies.

Author	Pre-Operative OA Grade	Post-Operative OA Grade	Pre-Operative Valgus Alignment (°)	Post-Operative Varus Alignment (°)	Other Pre-Operative Radiographic Outcomes	Other Post-operative Radiographic Outcomes
Baumgarten [12]	-	-	10.4 [FTA]	−2.4 [FTA]	IS ratio: 0.91 Tibial slope: 7.7° WB axis: 0.70	IS ratio: 0.98 Tibial slope: 7.3° WB axis: 0.34
Chambat [21]	-	-	8.0 [FTA]	-	-	-
Collins [13]	Severity graded, but data not available [KL]	Severity graded, but data not available [KL]	2.4 [HKA] 6.9 [FTA]	0 [HKA] 4.6 [FTA]	Tibial articular angle: 88.7° Tibial slope: 6.5° WB line offset: 60.2 %	Tibial articular angle: 86.4° Tibial slope: 7.5° WB line offset: 49.5 %
Coventry [7] **cited by Hallel** [9]	-	-	10.0 [FTA]	2.3 [FTA]	-	-
Giagounidis [38]	-	-	-	-	-	-
Hart [39] **cited by Hart** [40]	-	-	3.7 [HKA]	4.7 [HKA]	-	-
Hoorntje [23]	-	-	-	-	-	-
Jokio [14]	I = 3; II = 2; III = 3; IV = 2; V = 0 [AB]	-	3.5 [HKA]	1 [HKA]	-	-
Marti [15]	I = 14; II = 18; III = 2; IV = 0; V = 0 [AB]	I = 11; II = 22; III = 1; IV = 0; V = 0 [AB]	11.6 [FTA]	5.1 [FTA]	-	-
McCoy [25]	I = 2; II = 15; III = 2; IV = 0; V = 0 [AB]	-	27.0 [FTA]	4.5 [FTA]	-	-
Mirouse [18]	-	-	6.1 [HKA]	−0.5 [HKA]	mMDFA: 93.3° mMPTA: 92.8°	JLO: 9.0° mMDFA: 93.3° mMPTA: 86.3°
Puddu [27]	-	-	-	-	-	-
Shoji [16]	-	-	21.5 [FTA]	-	-	-
Surin [26]	-	-	-	-	-	-
Tjornstrand [41]	-	-	-	-	-	-
van Lieshout [17]	-	-	5.9 [HKA]	0.1 [HKA]	-	-
W-Dahl [24]	Severity graded, but data not available [AB]	-	8.0 [HKA]	2.0 [HKA]	-	-

[AB] Ahlbäck classification; [FTA] Femorotibial Angle; [HKA] Hip-Knee-Ankle Angle; IS – Insall-Salvati; JLO – Joint line obliquity; [KL] Kellgren-Lawrence classification; mMDFA - mechanical medial distal femoral angle; mMPTA - mechanical medial proximal tibial angle WB – weight-bearing.

3.3. Participant characteristics

The 17 papers included a total of 517 knees. The average number of knees examined across all studies was 30 (range: 6–113).

Nine studies (52.9 %) reported the male-to-female ratio (Table 2). The average number of males included across these studies was 11, compared to 27 female patients. The average age across the 11 studies that reported the variable was 50.1 ± 9.0 (range: 39–64). The mean reported BMI was 26.8 ± 0.6 (range: 26.1–27.5) however, this was only reported by four papers (23.5 %). Five papers studied both varus and valgus cohorts and therefore the demographic data from these papers have not been included in calculations of the overall mean.

With regards to the osteotomy performed, the most commonly reported approach was a medial closing wedge osteotomy (29.4 %), followed by lateral opening wedge osteotomy (11.7 %). One hemicallotasis (5.9 %) was also reported by W-Dahl [24] and one coronal plane osteotomy was reported by Baumgarten *et al.*[12]. Importantly, eight papers did not report the type of HTO performed (47.0 %) (Table 2). The average final follow-up ranged from 6 months to 21 years. The overall average follow-up was 64.4 ± 32.6 months (approximately 5.3 ± 2.7 years).

3.4. Radiographic outcomes

Five studies graded the radiographic severity of OA (29.4 %) (Table 3). Four used the Ahlbäck classification system and one used the Kellgren-Lawrence grading system [13–15,24,25]. Of these, one study combined the data with varus knee results, and another did not report the recorded grades. From the remaining three studies, a combined total of 19 knees were classified as Grade I (joint space narrowing < 3 mm), 35 as Grade II (joint space obliteration), 7 as Grade III (minor bone attrition 0–5 mm) and 2 knees qualified for Grade IV (moderate bone attrition 5–10 mm) pre-operatively. Post-operatively, Marti reported that 11 were classified as Grade I, 22 as Grade II and 1 as Grade III (1) [15]. Jokio stated that no knees exhibited obliterated joint space at 1-year; reduced from 3 knees pre-operatively [14]. No change was reported at the 2 year follow up. McCoy did not report Ahlbäck grade at final follow-up [25].

Despite the importance of knee alignment following HTO, this variable was only reported in 12 studies (70.6 %). Of the papers that reported knee alignment, the femorotibial angle (FTA) was used in 7 studies and the hip-knee-ankle angle (HKA) was used by 6 (Table 3). The mean pre-operative FTA was 13.6 ± 7.0° valgus (range 8.0 – 27.0°). This was corrected to 2.8 ± 2.9° varus post-operatively (range −2.4 – 5.1°). The HKA angle changed from 4.9 ± 1.9° valgus pre-operatively (range: 2.4 – 8.0°) to 1.2 ± 1.7° varus post-operatively (range: −0.5 – 4.7°).

Surprisingly, the alignment that the surgeons were aiming for was very rarely described. Under and overcorrection of alignment was only reported in two studies. Mirouse aimed to correct the HKA to 0-3° valgus [18]. Post-operatively, 8 knees were within the desired range, 4 (21.4 %) were overcorrected (<180°) and 7 (36.8 %) were under corrected (>183°). Jokio also reported overcorrection, stating at 3 months that 50 % of knees were within a range of ± 3°, but 20 % were under corrected and 30 % overcorrected [14]. After 1 year they reported no change. However, at 2 year follow up the percentage of alignments within ± 3° of the intended correction had reduced to 40 %, and overcorrection had increased to 40 %.

Other radiographic outcomes were very rarely reported in the literature (Table 3). Joint line obliquity (JLO) was only reported by one author, who stated the angle achieved post-operatively was > 10° in 5 patients (26.3 %) with an average of 7.8°. This increased to 6 patients (31.5 %) at final follow up (mean JLO = 9.0°) [18]. Furthermore, Insall-Salvati ratio was only reported in one study. The ratio increased post-operatively from 0.91 ± 0.16 to 0.98 ± 0.13 [12].

Tibial slope was reported in two studies. The slope increased by 1.0° in Collins' patient cohort, but reduced by 0.2° according to Baumgarten (Table 3) [12,13]. Collins also reported the tibial articular angle, described as the angle formed by the tibial anatomic and mechanical axis and medial tangent to the tibial plateau. This variable reduced from 88.7 ± 2.1° pre-operatively to 85.9 ± 2.0° at 6 months and 86.4 ± 2.0° at final follow up [13].

The weight-bearing axis and weight-bearing offsets were reported by two studies. The weight-bearing axis was determined by drawing a line from the centre of the femoral head to the centre of the ankle mortise and measuring the distance from this line to the medial edge of the proximal tibia. The value was then divided by the width of the tibia [12].The offset was measured as a percentage of tibial width [13]. Baumgarten reported that the weight-bearing axis reduced by half between baseline and final follow up [12]. Collins reported the offset reduced from 60.2 ± 11.4 % to 48.3 ± 11.2 % at six-months to 49.5 ± 12.4 % at final follow up.

Finally, Mirouse reported the mechanical medial proximal tibial and distal femoral angles (mMPTA/ mMDFA). The mMPTA reduced by 6.0° post-operatively, but the mMDFA did not change [18].

3.5. Patient reported outcomes

A variety of patient reported outcome measures were utilized by 11 studies (64.7 %) (Table 4). Four studies reported post-operative satisfaction (23.5 %) [16,17,21,26]. Patient satisfaction was reported to be as high as 78 % in one study, compared to 24 % in another (Table 4). This study found the poor satisfaction rates to be 47 % when measured subjectively and 65 % when measured objectively [26].

Table 4
The subjective and objective clinical outcomes of HTO for valgus knees according to the articles included in this review.

Author	Mean Pre-Operative PROM	Mean Post-Operative PROM	Return to Sport	Pre-Operative RoM	Post-Operative RoM	Pre-Operative Gait	Post-Operative Gait
Baumgarten [12]	*IKDC:* Nearly normal function = 50 %; Abnormal function = 17 %; Severely abnormal function = 17 %	*IKDC:* Nearly normal function = 50 %; Abnormal function = 34 % *Tegner:* 4.8 *HSS:* 90.0	-	0 – 130°	0-135°	-	-
Chambat [21]	-	*Satisfaction:* Good = 42 % Very Good = 30 % *Pain score:* Improvement = 91 %	-	-	-	-	-
Collins [13]	*LEFS:* 48 *KOOS:* 51.3 *SF-12P:* 41.6 *SF-12 M:* 51.9	*LEFS:* 61.8 *KOOS:* 41.6 *SF-12P:* 49.9 *SF-12 M:* 50.0	13 % athletes had returned to play by final follow-up	-	-	KAM – 1.27 % BW*Ht	KAM – 1.90 % BW*Ht
Coventry [7] **cited by Hallel** [9]	-	*Pain score:* No/Occasional mild pain = 77 %	-	-	-	-	-
Hoorntje [23]	-	-	84 % patients had returned to play by final follow-up	-	-	-	-
Jokio [14]	-	*Function score:* Good function = 80 %; Fair function = 10 %; Poor function = 10 %	-	3.5° extension	1.0° extension	-	-
Marti [15]	-	*Insall:* 84 *L&G:* Excellent = 26 %; Good = 62 %; Fair = 3; Poor = 3 %	-	5.4–126.6°	5.9–124.8°	-	-
Mirouse [18]	*IKS knee:* 46.0 *IKS function:* 56.6	*Global IKS score:* <140 in 10 patients	-	-	-	-	-
Puddu [27]	*HSS:* 60	*HSS:* 87	-	-	-	-	-
Shoji [16]	-	*Pain score:* Little/no pain = 53 %; Partial pain relief = 14 %; No change to pain = 33 % *Instability:* 8 patients *Satisfaction:* Satisfied = 57 %; Unsatisfied = 43 %	-	-	86 % retained/ improved flexion 14 % lost flexion 46 defined as having adequate RoM	All patients showed medial thrust	28 patients showed lateral thrust
Surin [26]	-	*Subjective Satisfaction:* Satisfied = 24 %; Improved = 29 %; Poor = 47 % *Objective satisfaction:*	-	1 patient < 60° 2 patients 65-80° 14 patients > 80° 2 patients –	-	-	-

Table 4 (*continued*)

Author	Mean Pre-Operative PROM	Mean Post-Operative PROM	Return to Sport	Pre-Operative RoM	Post-Operative RoM	Pre-Operative Gait	Post-Operative Gait
		Excellent = 12 %; Good = 23 %; Poor = 65 %		contracture of 10° 1 patient – contracture of 25°			
van Lieshout [17]		*Satisfaction:* Satisfied = 78 %; Unsatisfied = 14 %; Unsure = 0.9 % *KOOS:* Pain = 68.7 Symptoms = 67.5 Sport = 73.5 QoL = 31.7 *SF-36:* Physical functioning = 65.7; Role physical = 70.4; Body pain = 58.0; General health = 63.1; Vitality = 61.9; Social functioning = 74.7; Role emotional = 82.3; Mental health = 76.5; Physical Health Domain = 63.8; Mental Health Domain = 71.7 *IKDC:* 54.5 *L&G*: 64.5	-	-	-		

HSS – Hospital for Special Surgery Score; IKDC – International Knee Documentation Committee Score; IKS – International Knee Society Score; KAM – Knee adductor moment; KOOS – Knee Osteoarthritis Outcome Score; L&G: Lysholm & Guillquist Score; PROM – Patient reported outcome measure; RoM – Range of motion; LEFS – Lower extremity function scores; SF-12 M – SF-12 Mental function; SF-12P – SF-12 Physical function.

Post-operative pain was reported in 4 studies (23.5 %) [9,16,17,21]. Various methods were used to report pain, including the Knee Osteoarthritis Outcome Score (KOOS) and SF-36. The studies reported 67–91 % of subjects felt their pain levels had improved post-operatively. However, it appeared that approximately 30 % continued to feel pain at their final follow-up.

Function was subjectively reported as a discreet variable by Jokio, and as part of SF-36, International Knee Documentation Committee (IKDC), and lower extremity function scores (LEFS) by Baumgarten, van Lieshout and Collins [12–14,17]. Good function was reported in up to 80 % patients in Jokio's study, and Collins found LEFS improved post-operatively. The IKDC awards grades function A (normal) > 90 %, B (nearly normal) 89–76 %, C (abnormal) 75–50 % and D (severely abnormal) < 50 %. van Lieshout and Baumgarten's post-operative IKDC data suggests their patients continued to have abnormal function at final follow-up (Table 4) [12,17]. However, Baumgarten's Tegner scores contradicted these findings. The Tegner Activity Scale assesses activity, focusing on work and sports. Zero equates sick leave or disability due to knee problems, and 10 equates to being a national level athlete (football or rugby). The average post-operative score was 4.8, which correlates to work heavy labour and competing in competitive sports [12]. This agrees with Hoorntje's study that found 84 % of participants returned to sports by final follow-up [23]. However, only 2 athletes were able to return to sport 12 months post-operatively in Collins' study [13].

Multiple PROMs were used by studies included in this review; several were only reported in singular studies or post-operatively (Table 4). The Hospital for Special Surgery Score (HSS) was the only consistently used questionnaire. This PROM has sections on pain, function, range of motion, strength and instability with qualitative outcomes from excellent (>85) to poor (<60). Baumgarten reported a post-operative HSS of 90.0 ± 14.5 with 4 subjects scoring excellent, 1 scoring fair (60–69 points) and 0 poor [12]. This was consistent with Puddu, who noted an average improvement in HSS scores of 17 points post-operatively [27].

Although the KOOS and Lysholm & Guillquist scores were reported by more than one study, the results were reported in different formats and were therefore incomparable.

3.6. Biomechanical outcomes

Objective measurements of post-operative knee biomechanics were only reported in 6 papers (35.3 %) (Table 4). Range of motion (RoM) is the most common biomechanical variable measured clinically but was only quantified by 3 studies in this

Table 5
The reported complications and success rates of the procedure in the papers included in this review.

Author	Complications	Success Rate & Further Procedures
Baumgarten [12]		60–80 % at 5 years
		80 % did not require TKR within 5 years
Chambat [21]		
Collins [13]		38 % required further procedures. Two of the 11 procedures were TKRs at an average of 16.5 months
Coventry [7] **cited by Hallel** [9]		26 % required TKR at 9.8 years average
Giagounidis [38]		
Hart [39] **cited by Hart** [40]	1 non-union requiring bone-grafting and revision of internal fixation (5 %)	
Hoorntje [23]		10 % later underwent TKR; 2 % later underwent an MUA (mean follow up 42 months)
Jokio [14]	40 % had pre-operative subluxation – (0.5–1.0 cm) 30 % had post-operative subluxation	
Marti [15]	1 superficial wound infection (3 %); 1 thrombophlebitis (3 %); 3 apraxia of peroneal nerve with transient palsy (resolved within 1 year) (9 %)	1 arthrodesis due to disabling pain at 65 months (3 %)
McCoy [25]	1 delayed union (5 %); 1 non-union (5 %); 1 considered for TKR (5 %)	28 % symptom free 8 years post-op
	22 % considered failures at a mean follow up of 4.8 years	
Mirouse [18]	52 % considered as failures at a mean 4.3 years	5 year survival = 57.5 %
		70 % required TKR by final follow-up at 5 ± 2.7 years
Puddu [27]		
Shoji [16]	26 % developed subluxation; 4 % retained medial thrust	
Surin [26]		
Tjornstrand [41]		33 % required further surgery within 7 years
van Lieshout [17]	25 % were unstable at a mean of 4.5 years	5-year survival = 79.9 % 19 % required arthroscopy; 3 % required second HTO due to overcorrection; 12 % required TKR
W-Dahl [24]		33 % required TKR within 10 years

TKR – Total knee replacement.

review. Furthermore, only two reported both maximal flexion and extension pre- and post-operatively. The mean range of motion across both studies was calculated as 125.6° pre-operatively and 124.5° post-operatively.

Collins *et al.* were the only authors to undertake a gait analysis of patients following HTO for valgus knees [13]. The pre-operative peak external knee adduction moment across 12 patients was 1.27 ± 0.70 %BW*Ht. This increased 6 months post-operatively to 1.76 ± 0.70 %BW*Ht and to 1.90 ± 0.71 %BW*Ht at final follow up. Pre-operatively, the mean peak adduction on the contralateral limb was 2.18 ± 0.74 %BW*Ht and 2.12 ± 0.89 %BW*Ht post-operatively.

3.7. Complications and success rates

Nine studies (52.9 %) reported future surgical procedures after the initial HTO. Seven reported some of their patients underwent subsequent total knee replacements (TKR). The percentage of patients requiring TKR ranged from 10-70 %, however this variable was reported at different post-operative times. Reported success at 10-years was less variable at 26–33 %.

Other subsequent procedures, including revision of the original HTO, arthroscopy and manipulation under anaesthesia were less commonly reported, although some studies failed to clarify what further surgeries patients underwent (Table 5).

Failure of the procedure was categorised differently across the literature, leading to a range of 15–52 % being classes as failures. For example, Mirouse who reported the highest rate of failure defined it as a requirement of a TKA or an International Knee Score < 140. In many cases, where complications were reported, the HTO may have later been successful. Non-union, infection, subluxation and instability were commonly reported complications (Table 5). Complication rates varied from 3-30 %.

4. Discussion

This systematic review explored the radiographic, clinical and functional outcomes of high tibial osteotomy for the valgus knee to better understand the efficacy of the procedure. It is clear that there remains limited literature on the outcomes of HTO for valgus knees. Only seventeen papers were eligible for inclusion; 5 of which were published in the last 10 years. This

suggests not only that this procedure is actively being used in clinical practice, but that the continued use of this procedure is based on limited current research. The belief that further research is needed to improve current practice with regards to osteotomies of the knee is supported by the UK Knee Osteotomy Group's recent consensus statement[28].

In 1973, Coventry reported that HTO for valgus knees should only be performed on deformities < 12°[7]. The average pre-operative FTA across the studies that reported it was 13.6 ± 7.0° valgus (range 8.0 – 27.0°), suggesting that some procedures were carried out on deformities > 12° valgus. However, only two papers reported an FTA or HKA angle > 12° valgus; one which was published in the same year as Coventry's paper, and another which was published in 1985 [16,25]. More recent papers indicate the procedure is preferred for deformities < 12° valgus, conferring to the established indication for a HTO instead of a DFO [7,11].

Post-operatively, the FTA was corrected to an average of 2.8 ± 2.9° varus and the HKA angle was corrected to 1.2 ± 1.7° varus. This is in line with the recommendations made in the 1970 s and 1980 s that the ideal correction lies between 5° of valgus and 4° varus [7,25]. As a result, the cohorts presented in this review adequately represent the population of patients who would be defined as having undergone a successful HTO. The papers that reported pre- and post-operative alignments were mainly classified as 'good' quality. Interestingly, the 5 that failed to report this vital variable were all classified as 'Fair'. This suggests that the data presented in this review on post-operative alignment is valid.

Although most papers reported knee alignment, it was very unclear in the majority of studies what the planned alignment was. It is therefore difficult to infer at present whether the patient's outcomes are directly associated with the final alignment or not. This highlights the need for better reporting of planned and achieved alignments.

Over- and under-correction were reported in two good quality studies. Surprisingly, 58.2 % of patients in Mirouse's study were not within the target FTA range post-operatively [18]. This highlights the difficulty in accurately executing the operative plan. Recent innovations in combining the weightbearing long leg radiographs and lower limb CT scans have enabled the production of effectively weightbearing CT scans allowing 3D planning for osteotomies [29]. The introductions of navigation technology, and patient specific cutting guides have shown significant improvements in accuracy and reliability of achieving the desired correction of varus deformity in medial OA cases in high tibial osteotomy in comparison to the conventional techniques reported upon [30–33]. Accurate corrections for varus OA have been shown to significantly improve longevity of satisfactory results [34].

Application of these technologies may well address the difficulties in accurately executing the operative plans using the conventional techniques reported in the studies reviewed in this document, enabling varising osteotomies addressing latertal compartment OA to be able to deliver more consistent outcomes and improved longevity.

However, given the limited data on the relationship between the final alignment and outcome it could be that the range of acceptance in terms of alignment is currently too narrow. It may therefore be feasible to have a more flexible planned alignment without impacting the final outcome. Further research is needed to identify this window.

Post-operative misalignment may lead to complications which could contribute to failure. One of the most commonly reported complications that contributed to failure is post-operative subluxation. Post-operative subluxation is caused by an abnormal joint line and was reported in roughly 30 % of participants in 2 studies included in this review [14,16]. The oblique joint line should be corrected to < 10° to reduce the likelihood of subluxation and subsequent failure [11]. The average reported tibial slope in this review was 7.4°, but only two papers reported the variable [12,13]. According to Mirouse's study, 52 % of their patients were considered to have a failed HTO at final follow-up; of this 52 %, 26.3 % had a joint line obliquity > 10° [18]. This supports the current literature that failure is associated with an abnormal joint line [11]. All studies that supported the importance of maintaining a joint line obliquity < 10° were of good quality, suggesting that this is an important variable to consider when undertaking a HTO in a valgus knee. The relationships between other radiographic variables and post-operative complications warrant further investigation as the evidence is currently lacking or only available in poorer quality papers that may be subject to conflict of interest.

Ultimately, one of the main purposes of a HTO is to delay the need for a TKR. This review has found that overall, 10 % of patients required TKRs following HTO at any stage of follow-up [12,13,23,24,35]. At 5-years, the rate ranged from 20-70 %, and then 26–33 % at 10-years. The wide range seen in the 5-year rate was surprising given the good quality of both studies that reported this variable. It is therefore obvious that there is a lack of clarity in the current literature on the rates of revision to TKR. This can only lead us to conclude that further research is needed in this area.

Although long-term survival rates are important to patients, their perception of success relies heavily on the clinical and functional outcomes of the procedure. In patients with osteoarthritis of the knee, pain is a severely limiting factor for daily function and quality of life. However, only 4 studies specifically reported pain in this review (23.5 %) [9,16,17,21]. Chambat reported 91 % of patients had improvement in pain, but data from the other studies suggested that at least 23 % continued to experience some pain post-operatively. Nevertheless, the lack of available baseline measurements of pain and the varied outcomes used by those reporting this variable means it is currently not possible to fully understand the efficacy of this procedure at relieving pain in the knee. The quality of the papers reporting pain was also variable.

Subjective measures of function appeared to improve post-operatively, but there was some evidence of the level of objectively measured function remaining variably abnormal post-operatively. Objective measures of function were only reported in 6 papers. Although the extension deficit in the knee may improve post-operatively, the overall RoM appeared to stay the same or at best present minor improvements following HTO for the valgus knee. This is supported by Shoji's study that stated that most patients retained or improved the RoM post-operatively [16]. Importantly, the post-operative RoM remained

above 110° in the studies that quantified it. This is sufficient RoM to undertake most activities of daily living [36]. All studies that quantified RoM were of good quality.

Only one study performed a gait analysis of patients following HTO for valgus knees. Realignment of the limb by HTO resulted in an increase in the peak external knee adduction moment, indicating a medial shift in the loading of the knee joint. However further research is needed to support these findings and investigate the long-term biomechanical outcomes of HTO for valgus knees.

The overall satisfaction rates reported in the studies included in this review suggested that satisfaction varies across cohorts greatly. Nevertheless, at least 14 % were unsatisfied post-operatively. This is comparable with many TKR studies that report post op dissatisfaction of around 18 % [37]. Dissatisfaction following HTO may result from continued pain, poor function or unrealistic expectations. It should be noted however, that the quality of the papers reporting satisfaction was variable.

The main limitations to this systematic review is that there is a lack of literature on this specific topic. A potential explanation for this is the comparative rarity of lateral compartment OA, which totals 10 % of all cases of knee osteoarthritis. Furthermore, of the 17 papers included in this systematic review, many were case series with very small sample sizes. While the quality of many papers was categorized as 'good', these limitations must be considered when interpreting the findings of this review.

Furthermore, the studies included used a variety of different outcome measures. This was especially true for the patient reported outcomes. As a result, synthesising the data in an appropriate manner was challenging. All efforts were made to pool and group like-for-like data so that the body of literature could be adequately interpreted. In some cases, it was not possible or feasible to include all data in our analyses due to the varying nature in which the data was presented in papers. For example, RoM was occasionally quantified as a definitive value (e.g. RoM of 121°), and other times was quantified by a range (e.g. RoM of > 120°). It was therefore not possible to include all available data in our calculations of the mean of a variable. Although we ensured to include all data in our tables, not being able to include all available data in our analyses means that the average values presented in this review are not be truly representative of all patient cohorts.

Furthermore, the fact that variables were published in variable formats, or that different PROMs were used to assess the same outcomes made interpreting the overall findings particularly difficult. This review has therefore highlighted the need to standardise the outcome measures used to assess the efficacy of HTO. The UK Knee Osteotomy Registry (UKKOR) uses six patient reported outcome measurements (PROMs): Oxford Knee Score, Oxford Knee Score Activity & Participation Questionnaire, EQ Visual Analogue Scale, EQ-5D and Knee Injury and Osteoarthritis Outcome Score (KOOS) [4]. The reasoning behind this is to facilitate comparison of data across national and international cohorts. In this review the KOOS was the only questionnaire included from the suggested UKKOR PROMs, and even then, it was only reported by 2 papers. A suggestion to improve PROMs reporting would be to have a baseline set of tests and questionnaires specifically for patients undergoing HTO for both valgus and varus knees. This system would enable a more comprehensive comparison of data and outcomes both pre- and post-operatively in both lateral and medial OA patients. It is a limitation that many of the papers preceded UKKOR and any consensus on which scores to use.

Finally, it may be argued that additional papers not included in this review have reported the outcomes of HTO for valgus knees. However, these were excluded from this review as it was impossible to extract the appropriate information from the studies, as they combined the demographics and results of patients with varus and valgus deformities. This highlights the need for further research on patient cohorts with valgus knees.

5. Conclusions

There remains limited literature on the outcomes of HTO for valgus knees. Of the available literature, some failed to report the pre- and post-operative alignment of the joint, and most failed to define their planned alignment. This is surprising, given the nature and purpose of a HTO.

The studies included in this review were of varying quality. Thus, it is not possible to draw definitive conclusions from the current data. Further research into clinical, functional and radiological outcome of HTO for the valgus knee, as well as comparison with other techniques of treating valgus OA is thus needed. However, it appears that failures may occur due to subluxation, and therefore the need to address the slope as well as correction of the valgus (whilst avoiding joint line obliquity above 10°) is highlighted.

Importantly, the lack of available literature currently makes it difficult to determine not only the incidence of failure or poor outcome, but whether poorer outcomes following HTO are associated with the final achieved alignment. It is therefore essential for future research to define what post-operative alignment constitutes a good outcome. Studies of this nature must use consistent outcome measures to enable further systematic reviews in future.

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