European Journal of Orthopaedic Surgery & Traumatology (2018) 28:1381–1389
https://doi.org/10.1007/s00590-018-2199-6

ORIGINAL ARTICLE • KNEE - OSTEOTOMY

Survival and functional outcome of high tibial osteotomy for medial knee osteoarthritis: a 10–20-year cohort study

A. F. Y. van Wulfften Palthe[1] · N. D. Clement[2] · O. P. P. Temmerman[1] · B. J. Burger[1]

Received: 5 February 2018 / Accepted: 28 March 2018 / Published online: 12 April 2018

Abstract

Background The primary aim of this study was to identify independent predictors of long-term survivorship after high tibial osteotomy (HTO). The secondary aims were to describe the functional outcome of surviving HTO 10–20 years after surgery.

Methods A retrospective cohort of 223 HTO that were performed for the treatment of medial osteoarthritis was identified. Details were recorded from the patient notes. All surviving patients were contacted and asked to complete a Tegner Activity Scale, Lysholm Knee Score and rate pain using the Visual Analogue Scale (VAS). Survival analysis was performed, using conversion to arthroplasty as the definition of failure.

Results The mean age was 54 years (24–80 years). There were 123 (55.2%) in males and 100 (44.8%) in females. The mean BMI was 27.2 (SD 3.9). Twenty (9%) patients were lost to follow-up. The mean follow-up was 12 (SD 4) years. Survival at 10 years was 75 and 55% at 15 years and less than 40% at 20 years. Cox regression analysis demonstrated age of 50 years or more, female gender and surgical technique to be significant independent predictors of failure. The median Tegner score was 3 (inter-quartile range (IQR) 1–3). The mean Lysholm score was 75.5 (SD 18.4). The median VAS was 5 (IQR 0–6).

Conclusions The medium- to long-term survival and functional outcome after HTO was good to excellent at 10–20 years of follow-up. Age, gender, surgeon and surgical technique were identified as independent predictors of failure.

Keywords Knee · Tibia · Arthritis · Osteotomy · Technique · Survival

Introduction

High tibial osteotomy (HTO) is an accepted treatment for physically active patients with symptomatic isolated medial compartment osteoarthritis of the knee [1]. The medialisation of the mechanical axis of lower limb through the medial compartment of knee, due to progression of osteoarthritis in the medial compartment, is thought to result in overloading of the medial compartment with acceleration of symptoms and disease. The goal of a HTO is to overcorrect the mechanical axis of the lower limb in order to unload the medial compartment and load the non-diseased lateral compartment [2]. Successful osteotomy has been demonstrated to reduce pain and improve function [1]. A review by Bonasia et al. [3] reported survival rates at 5 years (75–94%), 10 years (51–95%) and 15 years (30–90%) of follow-up, using different techniques. HTO has become less popular in recent years possibly because of the gaining popularity of the unicompartmental knee arthroplasty (UKA), although UKA has not been shown to offer better outcomes than a HTO [2].

The current evidence for survivorship and functional outcome after HTO and independent predictors of these are limited, and the current evidence is generally composed of relatively small retrospective case series assessing one or two methods of HTO. Identification of independent predictors of survival and functional outcome after HTO, in addition to assessing the techniques used, would enable patients with the longer survivorship and improved functional outcome to be identified.

The primary aim of this study was to identify independent predictors of long-term survivorship after HTO performed for medial compartment osteoarthritis of the knee. The secondary aims were to describe the functional outcome

✉ A. F. Y. van Wulfften Palthe
alexanderpalthe@gmail.com

[1] Department of Orthopaedics, Noordwest Ziekenhuisgroep, Wilhelminalaan 12, 1815 JD Alkmaar, The Netherlands

[2] Department of Orthopaedics and Trauma, The Royal Infirmary of Edinburgh, 51 Little France Dr, Edinburgh EH16 4SA, UK

of surviving HTO and identify independent predictors of outcome 10–20 years after surgery.

Patients and methods

Cohort

The patient cohort was retrospectively identified from a patient database held at the study centre. All patients undergoing a HTO between January 1992 and July 2002 for the treatment of symptomatic medial compartment osteoarthritis of the knee were included. HTO performed in patients with post-traumatic malalignment of the knee or age under 18 years was excluded. Patient demographics, body mass index (BMI), date and side of operation, surgeon and operative technique were recorded from the patient notes. Standardised pre- and postoperative radiographs of the knee were assessed by an independent observer (AFYWP), and tibiofemoral angles were measured. During the study period, there were 223 consecutive osteotomies in 223 patients that met the inclusion criteria. The mean age was 54 years (range 24–80 years). There were 123 (55.2%) in males and 100 (44.8%) in females. The mean BMI was 27.2 (standard deviation (SD) 3.9).

Operative techniques

During the study period, there were five different HTO techniques employed to correct the varus alignment. All procedures were performed by one of 13 consultant orthopaedic surgeons.

Open wedge osteotomy

Open wedge osteotomy was performed medially approximately 4 cm below the joint line using the image intensifier. The osteotomy was gradually opened to preserve a bony bridge laterally in line with the joint line. The amount of opening of the osteotomy was calculated preoperatively using the radiographs. The osteotomy gap was filled with calcium phosphate and was then fixed with a locking plate. Full weight bearing was permitted.

Closed wedge osteotomy

After releasing the extensor muscles at the level of the proximal fibula, an oblique osteotomy of the head of the fibula was performed, thus preserving the proximal tibiofibular joint. The transverse tibial osteotomy was made approximately 2 cm below the joint line. A second cut was made, creating a wedge with a pre-calculated size. The wedge was then resected, and the osteotomy was fixed with a conventional compression plate. Full weight bearing was permitted.

Dome osteotomy

A dome-shaped osteotomy was achieved by drilling multiple holes from anterior to posterior in a dome-shaped fashion in the proximal metaphysis of the tibia. These were connected using a chisel. Re-alignment was achieved using preoperative radiographs and the image intensifier during surgery. Postoperatively, a leg cylinder cast was applied in which full weight bearing was permitted.

Hemicallotasis

Using the preoperative AP radiographs of the weight bearing leg, the length of callotasis and the period of elongation were calculated. Under an image intensifier, the first pin was inserted 7 mm below the joint line, parallel to the tibia plateau and the posterior cortex of the plateau. The distal pins were inserted utilising a template, and two other pins for the proximal group were inserted. After all pins were set, the medial cortex of the tibia was cut with a chisel at the middle of the tibial tuberosity leaving the lateral cortex intact. After checking that a mild valgus stress opened the osteotomy site under an image intensifier, a hemicallotasis device was applied. The patients were allowed to fully weight bear postoperatively. After 2 weeks, the hemicallotasis was started at a speed of 0.25 mm over 4–6 h. During elongation, weight bearing on the leg was not allowed.

Chevron transfixation

First, using an oscillating saw, an oblique osteotomy of the fibula was performed through a lateral incision at the level of the lower one third of the fibula.

Through a small incision at the lateral side of the knee, a pin was placed parallel to the joint surface of the proximal tibia using the image intensifier. A second pin was drilled 5–10 cm distal to the first pen, also with a lateral starting point. This second pin was aimed distally at a predetermined angle in order for it to run parallel to the first pen after the osteotomy and correction were performed.

An S-shaped incision over the anterior aspect of the proximal tibia was utilised to approach the proximal tibia. With the oscillating saw, an inverted *V*-shaped osteotomy was made, with the apex of the osteotomy proximal to the tibial tuberosity. The knee was then forced into valgus until the desired axis was achieved. An external compression device was applied to the Steinman pens, and compression was applied. Patients were allowed to fully weight bear. The external compression device and the pins were removed 6 weeks postoperatively.

Survival analysis

Failure was defined as a conversion to an arthroplasty of the treated knee, either unicompartmental or total knee arthroplasty (TKA). The patients' notes were reviewed to identify failures, and all were contacted to ensure no case of failure was missed.

Functional outcome

All patients were contacted and asked to complete a Tegner Activity Scale, a Lysholm Knee Score and their subjective current pain level in the knee. The Tegner Activity Scale is a validated score which ranges from 0 (sick leave or disability) to 10 (competitive sports) [4]. The Lysholm Knee Score is an accepted knee score in active patients where 0 is the worst score and 100 in the best, which can be categorised into: 0–64 bad, 65–83 reasonable, 84–94 good, 95–100 excellent [4, 5]. Pain at the time of follow-up was recorded using the Visual Analogue Scale (VAS) from 0 to 10 (0 no pain, 10 worst possible pain), rounded off to the nearest single digit.

Statistical analysis

Statistical Package for Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA) was used to analyse the data. An unpaired Student's t test and analysis of variance (ANOVA) were used to compare linear variables between groups. Pearson's correlation was used to assess the relationship between linear variables. Dichotomous variables were assessed using a Chi-square test. Kaplan–Meier methodology and a life table were used to investigate survival [6, 7]. Cox regression analysis was used to identify independent predictors of survival, entering all variables that were significant or demonstrated a trend towards on univariate analysis. Linear regression was used to identify independent predictors of functional outcome at final follow-up using enter methodology. A p value of ≤ 0.05 determined statistical significance.

Results

The majority of the osteotomies were performed using the Chevron transfixation technique ($n = 119$, 53%). There was a relatively even distribution of patients undergoing the other four techniques [open wedge osteotomy ($n = 14$, 6%), closing wedge osteotomy ($n = 35$, 16%), dome osteotomy ($n = 24$, 11%) and hemicallotasis ($n = 31$, 14%)]. The mean preoperative tibiofemoral angle was 178.6 (SD 3.3) degrees, which was significantly (difference 8.7, 95% confidence interval (CI) 7.6–15.1, $p < 0.001$, t test) changed to 187.3 (SD 4.0) degrees postoperatively. During the follow-up period, 18 patients had died, of which 3 had been converted to arthroplasty prior to their death. Twenty (9%) patients were lost to follow-up. There was no significant difference in age, gender, BMI or preoperative radiographic severity of those lost to follow-up and the study cohort ($p > 0.1$). The mean follow-up was 12 (SD 4) years.

Survival

There were 98 conversions to TKA during the follow-up period; the main indication was increasing pain. The survival rate at 10 years was 75 and 55% at 15 years (Fig. 1, Table 1). The survival rate was less than 40% at 20 years, but this may be skewed due to the limited numbers of patients followed up at this time point ($n < 50$). There was no point in time at which the rate of conversion to total knee arthroplasty increased, with a gradual diminishing survival rate being observed (Fig. 1).

Univariate analysis demonstrated female gender, surgeon and surgical technique to be significant predictors of failure (Table 2). There was also a trend towards significance demonstrated for older age (patients ≥ 50 years) to be associated with conversion. BMI and pre- and postoperative anatomical axis were not associated with conversion to total knee arthroplasty. Cox regression analysis demonstrated age of 50 years or more, female gender and surgical technique to be significant independent predictors of failure when adjusting for confounding variables (Table 3). There was a trend towards early conversion in the patients 50 years old or more during the first 5 years after surgery, after which the annual revision rate remained comparable for both age groups (Fig. 2). Female patients were significantly more likely to undergo conversion, with a survival rate of 61 and 46% compared to 72 and 61% for males at 10 and 15 years of follow-up, respectively (Fig. 3). Chevron transfixation technique had an observed superior survival rate compared to all other techniques (Fig. 4); however, only callus distraction and opening wedge techniques demonstrated a significantly worse survival when compared to chevron technique (Table 3).

Functional outcome and pain

Functional outcome and pain data were available for 82 patients of the 125 that had not undergone conversion to arthroplasty at a median follow-up of 13 years (range 9–19). The median Tegner score was 3 (inter-quartile range (IQR) 1–3). The mean Lysholm score was 75.5 (SD 18.4). The median VAS for pain was 5 (IQR 0–6). Univariate analysis for predictors of functional outcome, according to the Lysholm score, demonstrated no significant variable (Table 4). On entering all variables into a linear regression model, no variable demonstrated significance ($p > 0.23$) when adjusting for confounding.

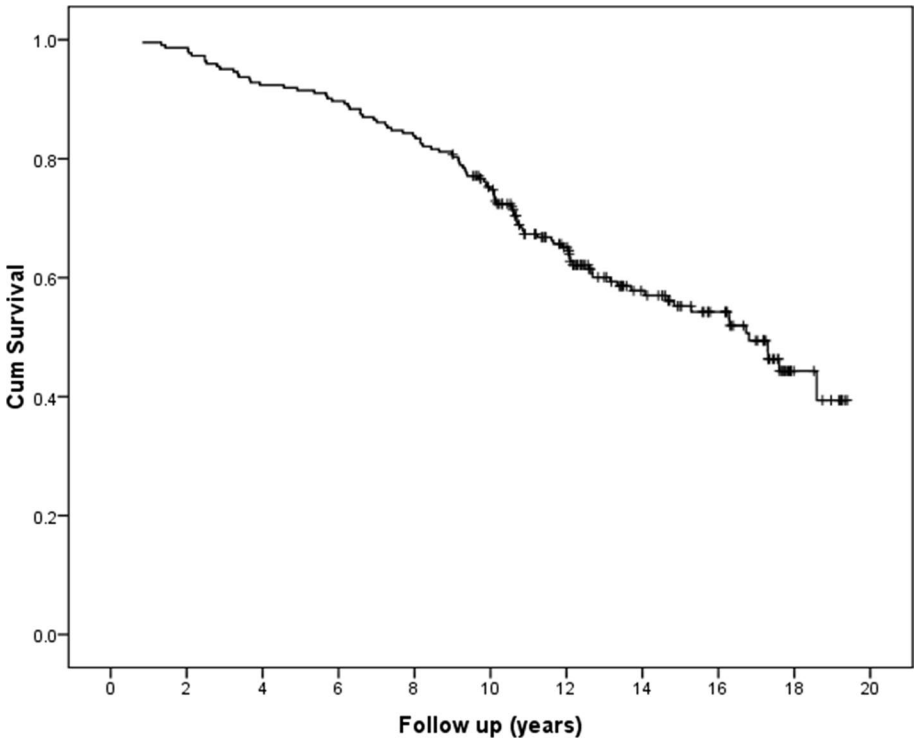

Fig. 1 Kaplan–Meier survival curve for the study cohort

Table 1 Life table for the cohort

Years	Number at start	Withdrawn	Number at risk	Failure	Proportion terminating	Proportion surviving	Survival	95% CI	
								Upper	Lower
0–1	223	0	223	1	0.4	99.6	99.6	100.0	97.6
1–2	222	0	222	2	0.9	99.1	98.7	100.0	96.3
2–3	220	0	220	8	3.6	96.4	95.1	97.4	92.7
3–4	212	0	212	6	2.8	97.2	92.4	94.8	90.0
4–5	206	0	206	2	1.0	99.0	91.5	94.2	88.8
5–6	204	0	204	4	2.0	98.0	89.7	92.5	86.9
6–7	200	0	200	7	3.5	96.5	86.5	89.3	83.8
7–8	193	0	193	6	3.1	96.9	83.9	86.6	81.1
8–9	187	0	187	7	3.7	96.3	80.7	83.4	78.0
9–10	180	8	176	12	6.8	93.2	75.2	77.8	72.6
10–11	160	15	152.5	16	10.5	89.5	67.3	69.6	65.0
11–12	129	12	123	4	3.3	96.7	65.1	67.5	62.8
12–13	113	21	102.5	8	7.8	92.2	60.0	62.2	57.9
13–14	84	10	79	3	3.8	96.2	57.8	60.0	55.6
14–15	71	9	66.5	3	4.5	95.5	55.2	57.3	53.0
15–16	59	7	55.5	1	1.8	98.2	54.2	56.6	51.8
16–17	51	9	46.5	4	8.6	91.4	49.5	51.7	47.3
17–18	38	25	25.5	3	11.8	88.2	43.7	45.7	41.7
18–19	10	3	8.5	1	11.8	88.2	38.5	40.5	36.6
19–20	6	6	3	0	0.0	100.0	38.5	40.6	36.5

Table 2 Patient demographics, surgeon and technique according to survival

Predictor	Survived		Odds ratio	95% CI		*p* value
	No ($n=125$)	Yes ($n=98$)		Lower	Upper	
Age (*n*)						
< 50 years	47	25	1.76	0.98	3.15	0.06
≥ 50 years	78	73				
Gender (*n*)						
Male	78	45	1.96	1.14	3.35	0.01
Female	47	53				
BMI (mean, SD)	27.4 (4.0)	27.1 (3.9)	0.2	− 1.5	2.0	0.79
Tibiofemoral angle						
Pre-op	178.4 (3.2)	178.4 (3.2)	0.7	− 0.3	1.8	0.18
Post-op	187.9 (5.1)	186.6 (5.5)	1.3	− 0.8	3.4	0.21
Surgeon (*n*)						
1	15	20	–	–	–	0.008
2	17	10				
3	8	15				
4	17	7				
5	11	2				
6	1	0				
7	1	6				
8	15	5				
9	25	18				
10	2	0				
11	12	11				
12	1	3				
13	0	1				
Technique (*n*)						
Chevron	74	45	Reference			
Callus	12	19	2.60	1.16	5.87	0.03
Dome	13	11	1.39	0.57	3.37	0.46
Closing	19	16	1.38	0.65	2.96	0.40
Opening	7	7	1.64	0.54	5.00	0.40

Table 3 Cox regression analysis to identify independent predictors of survival after HTO for the cohort

Variable	Hazard ratio	95% CI		*p* value
		Lower	Upper	
Age				
< 50 years	Reference			
≥ 50 years	1.61	1.00	2.58	0.049
Gender				
Male	Reference			
Female	1.67	1.11	2.52	0.013
Surgeon	0.99	0.93	1.05	0.811
Technique				
Chevron	Reference			
Callus	4.22	2.34	7.62	0.000
Dome	1.68	0.85	3.32	0.137
Closing	1.63	0.91	2.92	0.098
Opening	2.57	1.13	5.86	0.025

Discussion

This study shows good to excellent survival rates for HTO at 10–20 years of follow-up. There was a gradually diminishing survival of 75% at 10 years to 55% at 15 years and 40% at 20 years. Patient age, gender, surgeon and surgical technique were demonstrated to be independent predictors of failure. Chevron transfixation technique showed superior survival rates, but a statistical significant difference was only found when compared to dome osteotomy and open wedge osteotomy. BMI and pre- and postoperative anatomical axis were not associated with conversion to arthroplasty. Early conversion to arthroplasty was observed in the age group under 50 years. Tegner score, Lysholm score and pain were found to be reasonable at follow-up. No statistical significance was identified after univariate analysis or regression analysis.

The main limitation of this study is the uneven distribution of patients over five different techniques; most

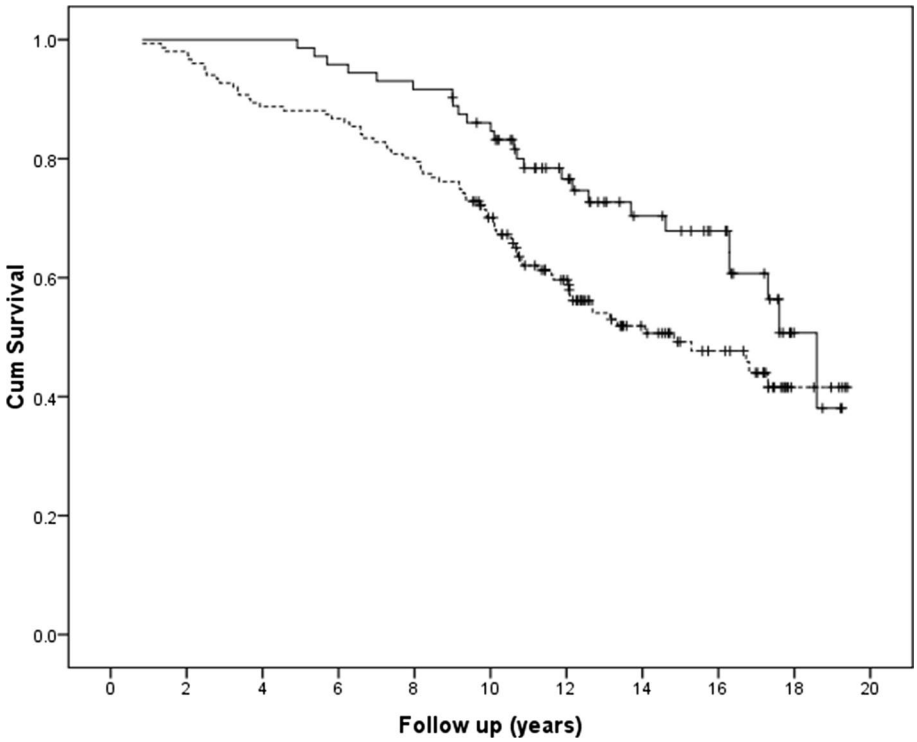

Fig. 2 Kaplan–Meier survival curve for patients < 50 years old (dashes line) and 50 years old or more (solid line) after HTO

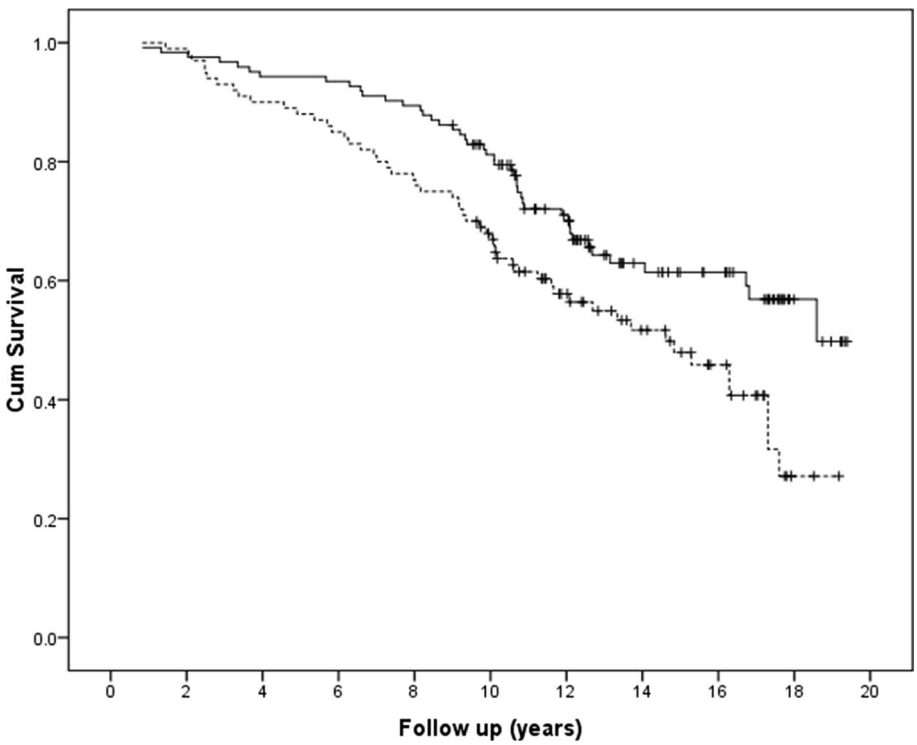

Fig. 3 Kaplan–Meier survival curve for female (dashed line) and male (solid line) patients after HTO

operations were performed using one technique (Chevron transfixation). Although this technique was favoured by many surgeons, the use of an external compression device and the subsequent necessity of removal of this device and the pins made that this technique has been abandoned with the opening wedge osteotomy gaining more recent popularity. The operations in this study were performed by 13 different surgeons. This is due to the fact that we recorded data from a large time frame in which the members of staff changed. However, we present a very large cohort of 223

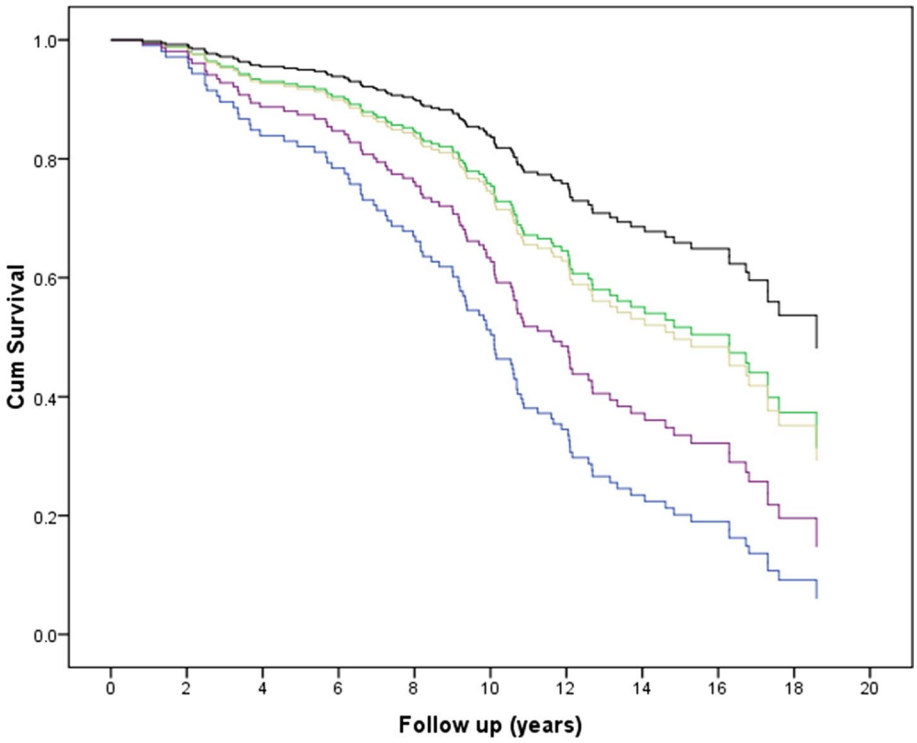

Fig. 4 Kaplan–Meier survival curve according to surgical technique after HTO: chevron (black), dome (green), closing wedge (grey), opening wedge (purple) and callus (blue) (colour figure online)

Table 4 Lysholm score at final follow-up according to patient demographics, surgeon and technique used for HTO

Predictor	Mean (SD)[a]	r^b	Difference	95% CI		p value
				Lower	Upper	
Age						
< 50 years	77.8 (19.2)		4.0	− 4.2	12.2	0.34
≥ 50 years	73.8 (17.8)					
Gender						
Male	77.6 (16.4)		4.5	− 3.2	12.2	0.25
Female	71.3 (21.4)					
BMI		− 0.19				0.12
Tibiofemoral angle						
Pre-op		0.09				0.49
Post-op		0.05				0.86
Surgeon						
$n = 12$						0.79
Technique						
Chevron	76.5 (18.2)					0.84
Callus	74.4 (20.7)					
Dome	67.6 (24.7)					
Closing	76.3 (17.9)					
Opening	76.3 (14.3)					

[a]Unpaired t test

[b]Pearson correlation

operations with an acceptable 9% of patients lost to follow-up and 18 patients who died. This is one of the largest cohort studies reporting the medium- to long-term survival and functional outcome of HTO in the literature.

Predictors of conversion to TKA are severe arthritis (Ahlbeck ≥ 3), advanced age (≥ 65), patellofemoral arthritis, decreased ROM, previous arthroscopic debridement's, joint instability, lateral tibial thrust, undercorrection,

overcorrection and loss of correction [3]. Howells additionally found that WOMAC scores above 45 and BMI under 30 were predictors of improved survivorship [8]. However, other studies found no association between BMI and survivorship [9]. Therefore, the indications for a HTO are young age (< 65 years), an active patient with isolated medial knee arthritis (less than III Ahlbeck), good range of motion and no ligamentous instability. The goal of the osteotomy should be to overcorrect the mechanical axis to 1–8 degrees of valgus [2, 3, 10]. The current study has shown that age above 50 years or more, female gender, surgeon and surgical technique were predictors of failure. BMI and pre- and postoperative anatomical axis were not associated with conversion to total knee arthroplasty in our study.

Bonasia et al. [3] performed a review of the survival of open wedge and closing wedge osteotomy in 2014. The survival rates for open wedge osteotomy were found to be 73–92% at 10 years and 71% at 15 years. Survival rates for opening wedge osteotomy in the current study were less than this with only 64% survival at 10 years and 45% at 15 years. The closing wedge osteotomy demonstrated survival rates of 79–97.6% at 10 years and 56–92.8% at 15 years, which again is greater than the current study of 77% at 10 years and 44% at 15 years. Naudie et al. [11] showed survival rates of 75% at 5 years, 51% at 10 years, 39% at 15 years and 30% at 20 years for the dome osteotomy. Whereas the current study found the survival rates to be greater than this, with 92% surviving at 5 years, 79% at 10 years and 58% at 15 years. For opening wedge osteotomy with hemicallotasis, Weale et al. [12] published survival rates of 89% at 5 years and 63% at 10 years. Our survival rates for this technique were 77% at 5 years and 41% at 10 years. The survival rates presented in this study for opening wedge, closing wedge and hemicallotasis are slightly lower compared to the rates found in current literature. Also, observed survival rates for the opening and closing wedge techniques showed a more rapid decline. However, for the dome osteotomy the survival rates were superior to what was found in current literature. To our knowledge, our study is the first to report on survival rates for the Chevron technique.

This study showed a median Lysholm score of 75.5 and a median Tegner score of 3 at 13 years follow-up. Bode 2015 found the average Lysholm score to be 76.6 at 60 months after high tibial osteotomy [13]. In the healthy population, Lysholm score was found to be 94 (range, 43–100), and the average Tegner activity level was 5.7 (range, 1–10) [14]. The postoperative Lysholm and Tegner scores for the reported cohort are in line with what is found in current literature. Although these scores are lower than for normal knees, we find these scores acceptable for the postoperative status. An Ahlbeck grade 0 arthritis of the lateral compartment and excellent preoperative Knee Society score are found to be related to a good functional outcome. Age above 65 years and postoperative knee flexion less than 120° were related to a poor functional outcome [3]. In current study, no independent predictors of functional outcome were identified. This probably due to the fact that those patients with symptoms went on to be revised to a TKA.

Numerous techniques of HTO have been described since Coventry first introduced the concept of HTO 45 years ago, describing his closing wedge osteotomy [15, 16]. According to his technique, a wedge of bone is removed on the lateral side in order to create a valgus correction for varus deformity. The closing wedge osteotomy is the golden standard. More recently, the opening wedge osteotomy has gained popularity because it was thought to be an easier technique with less complications [2]. To create valgus correction using this technique, a medial sided osteotomy is opened and fixed; augmentation can be used to fill the opened osteotomy. Other techniques include dome osteotomy, hemicallotasis opening wedge osteotomy and osteotomy 'En Chevron' [17–23]. Brouwer et al. [1] performed a systematic review but found no significant difference between effectiveness of different techniques of HTO in a systematic review. The most popular techniques currently are opening wedge and closing wedge osteotomies [2]. Duivenvoorden et al. [24] found no clinical or radiological difference in a randomized controlled trial comparing these techniques. However, they did find a higher conversion rate to TKR in the closed wedge group.

The current study is unique because of the size of the cohort and the fact that five different techniques are compared. Opening wedge, closing wedge and dome osteotomy are common techniques, and to authors knowledge this is the first study to present long-term follow-up data for hemicallotasis and Chevron transfixation. These techniques are no longer commonly used, due to the fact that an external distraction or compression device is necessary. The use of external devices yields the risk of pin tract infections. Also, in the case of hemicallotasis technique repetitive visits to the hospital are necessary for device adjustment. It is therefore understandable that opening- and closing wedge techniques have gained popularity in the last decades. The current study does show that the chevron technique, despite the use of an external device, has excellent survival rates, even better than opening or closing wedge at 10, 15 and 20 years.

Conclusion

Patients above 50 years old or more, of female gender, the surgeon and surgical technique are predictors of failure. At risk, patients should be made aware of their increased rate of failure of a HTO during the preoperative consent process, where alternative surgical options could be discussed. Survival rates were found to be in line with the rates found in the

current literature. Functional outcome and pain levels were found to be reasonable at long-term follow-up. This study confirms that HTO is an acceptable treatment for symptomatic medial osteoarthritis and refutes the decline in popularity of HTO that is seen nowadays.

Acknowledgements The authors thank Rinse Meester and Floor Kappelhof for their assistance in collecting data for this study.

Funding This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Brouwer RW, Huizinga MR, Duivenvoorden T, van Raaij TM, Verhagen AP, Bierma-Zeinstra SMA, Verhaar JAN (2014) Osteotomy for treating knee osteoarthritis. Cochrane Database Syst Rev 12:CD004019
2. Amendola A, Bonasia DE (2010) Results of high tibial osteotomy: review of the literature. Int Orthop 34:155–160. https://doi.org/10.1007/s00264-009-0889-8
3. Bonasia DE, Dettoni F, Sito G, Blonna D, Marmotta A, Bruzzone M, Castoldi F, Rossi R (2014) Medial opening wedge high tibial osteotomy for medial compartment overload arthritis in the varus knee: prognostic factors. Am J Sports Med 42:690–698
4. Lysholm J, Tegner Y (2007) Knee injury rating scales. Acta Orthop 78:445–453
5. Tegner Y, Lysholm J (1985) Rating systems in the evaluation of knee ligament injuries. Clin Orthop 198:43–49
6. Kaplan EL, Meier P (1958) Nonparametric estimation from incomplete observation. J Am Stat Assoc 53:457–481
7. Murray DW, Carr AJ, Bulstrode C (1993) Survival analysis of joint replacements. J Bone Joint Surg Br 75:697–704
8. Howells NR, Salmon L, Waller A, Scanelli J, Pinczewski LA (2014) The outcome at 10 years of lateral closing-wedge high tibial osteotomy: determinants of survival and functional outcome. Bone Joint J 96-B:1491–1497
9. Floerkemeier S, Staubli AE, Schroeter S, Goldhahn S, Lobenhoffer P (2014) Does obesity and nicotine abuse influence the outcome and complication rate after open-wedge high tibial osteotomy? A retrospective evaluation of five hundred and thirty three patients. Int Orthop 38:55–60
10. Lee DC, Byun SJ (2012) High tibial osteotomy. Knee Surg Relat Res 24:61–69
11. Naudie D, Bourne RB, Rorabeck CH, Bourne TJ (1999) Survivorship of the high tibial valgus osteotomy. A 10-to-22-year followup study. Clin Orthop Relat Res 367:18–27
12. Weale AE, Lee AS, MacEachern AG (2001) High tibial osteotomy using a dynamic axial external fixator. Clin Orthop Relat Res 382:154–167
13. Bode G, von Heyden J, Pestka J, Schmal H, Salzmann G, Südkamp N, Niemeyer P (2015) Prospective 5-year survival rate data following open-wedge valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 23:1949–1955
14. Briggs KK, Steadman JR, Hay CJ, Hines SL (2009) Lysholm score and Tegner activity level in individuals with normal knees. Am J Sports Med 37:898–901
15. Coventry MB (1973) Osteotomy about the knee for degenerative and rheumatoid arthritis: indications, operative technique, and results. J Bone Joint Surg 55-A:23
16. Jackson JP, Waugh W (1961) Tibial osteotomy for osteoarthritis of the knee. J Bone Joint Surg Br 43B:746–751
17. Chiang H, Hsu H, Jiang C (2006) Dome-shaped high tibial osteotomy: a long-term follow-up study. J Formos Med Assoc 105(3):214–219
18. Fowler JL, Gie GA, MacEachern AG (1991) Upper tibial valgus osteotomy using dynamic external fixator. J Bone Joint Surg Br 73-B:690–691
19. Magyar G, Toksvig-Larsen S, Lindstrand A (1998) Open wedge tibial osteotomy by callus distraction in gonarthrosis: operative technique and early results in 36 patients. Acta Orthop Scand 69:147–151
20. Turi G, Cassini M, Tomasi PS, Armotti P, Lavini F (1987) Directional osteotomy of the knee using hemicallotasis. Chir Organi Mov 72:205–209
21. Aglietti P, Rinonapoli E, Stringa G, Taviani A (1983) Tibial osteotomy for the varus osteoarthritic knee. Clin Orthop Relat Res 176:239–251
22. Mousa WFA (2014) Proximal tibial chevron osteotomy in treating adolescent tibia vara. Curr Orthop Pract 25(2):152–157
23. Greene WB (1993) Infantile tibia vara. J Bone Joint Surg Am 75(1):130–143
24. Duivenvoorden T, Brouwer R, Baan A, Bos P, Reijman M, Bierma-Zeinstra S (2014) Comparison of closing-wedge and opening-wedge high tibial osteotomy for medial compartment osteoarthritis of the knee: a randomized controlled trial with a six-year follow-up. J Bone Joint Surg Am 96(17):1425–1432