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A predictive score of high tibial osteotomy survivorship to help in surgical decision-making: the SKOOP score

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Abstract

Introduction The high tibial osteotomy (HTO) survival rate is strongly correlated with surgical indications and predictive factors. This study aims to assess HTO survival in the long term, to determine the main predictive factors of this survival, to propose a predictive score for HTO based on those factors.

Methods This multicentric study included 481 HTO between 2004 and 2015. The inclusion criteria were all primary HTO in patients 70 years old and younger, without previous anterior cruciate ligament injury, and without the limitation of body mass index (BMI). The assessed data were preoperative clinical and radiological parameters, the surgical technique, the complications, the HKA (hip knee ankle angle) correction postoperatively, and the surgical revision at the last follow-up.

Results The mean follow-up was 7.8 ± 2.9 years. The HTO survival was 93.1% at 5 years and 74.1% at 10 years. Age < 55, female sex, BMI < 25 kg/m^2 and incomplete narrowing were preoperative factors that positively impacted HTO survival. A postoperative HKA angle greater than 180° was a positive factor for HTO survival. The SKOOP (Sfa Knee OsteOtomy Predictive) score, including age (threshold value of 55 years), BMI (threshold values of 25 and 35 kg/m^2), and the presence or absence of complete joint line narrowing, have been described. If the scale was greater than 3, the survival probability was significantly lower ($p < 0.001$) than if the scale was less than 3.

Conclusion A predictive score including age, BMI, and the presence or absence of joint line narrowing can be a helpful in making decisions about HTO, particularly in borderline cases.

Level of evidence Retrospective cohort study. Level III.

Keywords High tibial osteotomy · Survival rate · Predictive factors · Predictive score · Age · BMI · TKA conversion

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Abbreviations

ACL	Anterior cruciate ligament
BMI	Body mass index
HKA	Hip knee ankle
HTO	High tibial osteotomy
mMDFA	Mechanical medial distal femoral angle
MPTA	Medial proximal tibial angle
ROM	Range of motion
SKOOP score	Sfa Knee OsteOtomy Predictive score
TKA	Total knee arthroplasty
UKA	Unicompartmental knee arthroplasty

Introduction

Unicompartmental medial knee osteoarthritis is a common condition and can represent a challenge in young and active patients [1]. Several surgical treatments are available: high tibial osteotomy (HTO), unicompartmental knee arthroplasty (UKA), and sometimes total knee arthroplasty (TKA) [2]. The ideal patient for HTO is usually young and active, with isolated osteoarthritis in the medial compartment and an associated constitutional varus deformity. Nevertheless, most indications are not perfect, and a compromise is necessary. A poor indication can lead to poor outcomes, such as persistent pain that requires knee arthroplasty or overcorrection with pain in the contralateral compartment for HTO and tibial loosening or polyethylene wear for UKA. Thus, knowledge of the predictive factors of failure is crucial to orient the therapeutic choice.

Several predictive factors should be considered before making a decision on surgery, such as age, sex, patient activity, and morphological or radiological parameters [3]. These predictive factors have already been studied in the literature and significantly impact HTO survival rates and the risk of conversion to TKA [3–6]. Indeed, the survival rates reported were variable and depended mainly on the indications. Studies with at least a 10-year follow-up reported 5-year survival rates from 73 to 99% and 10-year survival rates from 51 to 98%, with an average time to revision between 6 and 13 years [7–12]. Nevertheless, to our knowledge, no study has determined a predictive score or model to estimate the survival rate or the probabilities of success of HTO according to these predictive factors [6]. Some predictive models have been established to anticipate osteotomy correction [13], pseudoarthrosis risk [14] or functional outcomes in the short term [15]. Nevertheless, none assessed survival in the mid- or long term.

This study hypothesized that the main factors of HTO success or failure could be combined in a predictive score to help surgical indication. Therefore, the aims were (1) to assess HTO survival in the long term, (2) to determine the main predictive factors of this survival, and (3) to propose a predictive score for HTO based on the main predictive factors.

Materials and methods

Patients

This retrospective multicentric study included patients who underwent HTO between January 2004 and December 2015. The inclusion criteria were all primary HTO in patients 70 years old or younger. The exclusion criteria were anterior cruciate ligament (ACL)-deficient knees and associated HTO and ACL reconstruction. During this period, 481 HTO patients were included in five experienced centers. The surgeons with less than 10 HTO per year were excluded. The mean number of HTO by center and per year was 11.8 ± 2.1. The demographic data are summarized in Table 1.

Data assessment

All the patients were followed according to the same protocol in all the participating centers. The clinical and radiological data were collected preoperatively, during the surgery, and postoperatively (Tables 1 and 2). For the range of motion, full flexion was defined as greater than 120°. A flexion contracture was defined as a loss of full extension greater than 5°. The radiographic assessment included anteroposterior view, lateral view, and a long leg standing radiograph. The severity of osteoarthritis was assessed with the modified Ahlbäck classification [16]. Patients with stage 1 or 2 disease had incomplete joint line narrowing of the medial femorotibial compartment. Patients with stage 3 or 4 disease had complete joint line narrowing of the medial femorotibial compartment. Standardized radiographic measurements were performed: hip knee ankle (HKA) angle, mechanical medial distal femoral angle (mMDFA), and medial proximal tibial angle (MPTA) [17, 18]. Adverse events were recorded during follow-up and at the final assessment. All reoperations and revisions were also recorded, and the reason for the reoperation or the revision was documented.

Statistical analysis

The statistical analysis was performed with R Software on BiostTGV and XLstat (Version 2021.2.1, Addinsoft Inc., Paris, France). Patient characteristics were described using means, standard deviations, ranges for continuous variables, and counts (percentages) for categorical variables. The quantitative data were provided binaries to allow the comparison of survivorship in these two groups. The groups were generated according to the usual value classes in the literature. When no clear threshold value existed to determine

Table 1 Preoperative and preoperative demographic characteristics in the HTO cohort

Parameters HTO number (%) or mean ± SD [min–max]	*N* = 481 HTO
Preoperative data	
Gender (male)	328 (68.5%)
Age (years)	55.1 ± 7.9 [23.6–70.8]
Weight (kg)	83.1 ± 15.3 [45.0–135.0]
Height (m)	1.71 ± 0.09 [1.46–1.96]
Body mass index (kg/m^2)	28.6 ± 4.7 [14.7–44.3]
Side (right)	251 (53%)
Medical history	
None	208 (53.3%)
Meniscectomy	151 (38.7%)
Ligament surgery	13 (3.3%)
Osteochondritis	18 (4.6%)
Articular effusion	193 (47.7%)
Flexion contracture (°)	0.94 ± 2.4 [0–15]
Flexion (°)	130.8 ± 12.1 [90–150]
Ahlbäck classification	
Stage 1	61 (13.7%)
Stage 2	232 (52%)
Stage 3	153 (34.3%)
Stage 4	0
Kellgren classification	
Stage 1	67 (15%)
Stage 2	98 (21.9%)
Stage 3	224 (50.1%)
Stage 4	58 (13%)
HKA angle (°)	173.5 ± 3.1 [165–180]
Mechanical medial distal femoral angle (°)	90.7 ± 2.2 [79–98]
Medial proximal tibial angle (°)	85.5 ± 2.5 [77–91]
Data during the surgery	
Surgical technique (Medial opening/lateral closing)	342 (73.7%)/122 (26.3%)
Surgical planning (Standard/navigation)	434 (93.7%)/29 (6.3%)
Bone void filler	
None	107 (27.1%)
Autograft	44 (11.1%)
Allograft	58 (14.7%)
Bone substitute	186 (47.1%)
HTO fixation	
Locking plate	338 (72.8%)
Non-locking plate	91 (19.6%)
Blade plate	33 (7.1%)
Staples	2 (0.4%)
Per operative fracture	
None	419 (87.8%)
Hinge fracture	53 (11.1%)
Articular fracture	5 (1%)

HKA hip knee ankle angle; *HTO* high tibial osteotomy; *SD* standard deviation

Table 2 Postoperative data in the HTO cohort

Parameters HTO number (%) or mean ± SD [Min–Max]	*N* = 481 HTO
Postoperative HKA angle (°)	182.4 ± 3.2 [172–192]
Surgical revision	
Hardware removal	264 (54.9%)
Meniscal management	1 (0.2%)
Postop acute infection	5 (1%)
Late acute infection	1 (0.2%)
Nonunion	17 (3.5%)
TKA	102 (21.2%)

HKA hip knee ankle angle; *HTO* high tibial osteotomy; *SD* standard deviation; *TKA* total knee arthroplasty

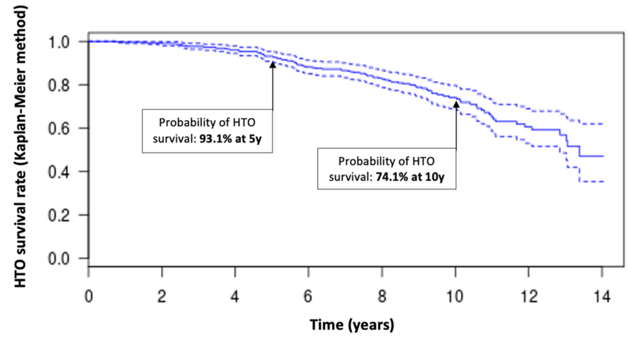

Fig. 1 HTO survival rate according to time (years) (Kaplan–Meier method)

the categories, a "trial and error method" allowed us to determine the value with the highest degree of significance. Kaplan–Meier survivorship analysis (with a 95% confidence interval (CI)) was performed with knee arthroplasty as the endpoint, defined as knee revision with total or unicompartmental knee arthroplasty. Univariate analysis was performed for each assessed factor. The preoperative factors with the highest significance level were isolated to select the most relevant factors to include in a predictive score of HTO survival. Several weightings of the score items were performed. The decision threshold for the score was determined by comparing groups 2 to 2 for each cutoff value using the log rank test and retaining the value for which the difference in probability of survival between the two groups was the greatest. The threshold value of significance was determined at 1%. A p value < 0.05 was considered statistically significant in each analysis, with a confidence interval of 95%.

Ethical approval

All the procedures were performed in accordance with the ethical standards of the institutional and/or national research committee, the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the IDRCP review board under IRB n°2018-A-01353–52.

Results

Cohort survival

The mean follow-up was 7.8 ± 2.9 years [1.1–14.0]. There were 102 failures (21.2%) with 80 lateral femorotibial osteoarthritis progressions (16.6%), 15 progressions of medial femorotibial osteoarthritis (3.1%), and 7 other reasons (1.5%). The mean delay of conversion to TKA was 84.4 ± 38.2 months [8.6–169.2]. In this cohort, the probability of HTO survival was 93.1% at 5 years, 85.2% at 7.5 years, 74.1% at 10 years, and 60.4% at 12 years (Fig. 1).

Univariate analysis

The predictive factors found in the univariate analysis are described in Table 3. An age less than 54 years, female sex, and incomplete narrowing of the joint line were preoperative factors that positively impacted HTO survival. For BMI, two threshold values (at 25 kg/m^2 and 35 kg/m^2) had a significant difference in HTO survival. The lower the BMI was, the higher the probability of good survivorship in the long term.

The presence of preoperative fracture had a negative impact on the probability of HTO survival. The surgical technique had no impact on the survival probability. A postoperative HKA angle greater than or equal to 180° was a positive factor for HTO survival.

SKOOP (Sfa knee osteotomy predictive) score

The SKOOP score included age (threshold value of 55 years), BMI (threshold values of 25 and 35 kg/m^2), and the presence or absence of complete or incomplete joint line narrowing (Table 4). Due to some missing data, the predictive score was calculated for 411 patients. If the scale was greater than or equal to 3, the survival probability at 5, 7.5 and 10 years was significantly lower ($p < 0.001$) than if the scale was less than 3 (Fig. 2 and Table 5).

Discussion

This study is the first to propose a daily practice score to help in decision-making for potential HTO surgery. The most important finding of the present study was the ability of the SKOOP score—based on age, BMI, and osteoarthritis severity—to anticipate HTO survival (Figs. 3 and 4).

Table 3 Univariate analysis of HTO survival (comparison with the log rank method)

Variable	Compared groups (Best survival rate in first)	*p* value
Preoperative parameters		
Gender	Female (vs. Male)	**0.011**
Age (years)	< 54 (vs. ≥ 54)	**0.003**
Body mass index (kg/m^2)	< 25 (vs. ≥ 25)	**0.009**
	< 35 (vs. ≥ 35)	**< 0.001**
Medical history	None (vs. yes)	0.230
Flexion contracture	None (vs. > 5°)	0.140
Flexion	Stiffness (vs. Full flexion)	0.185
Ahlbäck classification	Incomplete narrowing (vs. full narrowing)	**0.001**
Pre-op HKA angle (°)	< 177 (vs. ≥ 177)	0.112
Per operative parameters		
Surgical technique	opening (vs. closing)	0.714
Surgical planning	Standard (vs. navigation)	0.815
Bone void filler	Yes (vs. no)	0.210
HTO fixation	Locking plate (vs. other fixations)	0.901
Fracture during surgery	None (vs. fracture)	**< 0.001**
Postoperative parameters		
Postop HKA angle (°)	≥ 180 (vs. < 180)	**0.002**
	< 183 (vs. [183;185])	0.668
	[183;185] (vs. ≥ 186)	0.421
	[183;185] (vs. < 183 et ≥ 186)	0.768

Significant *p* bold values are ($p < 0.05$)

HKA hip knee ankle angle; *HTO* high tibial osteotomy; *SD* standard deviation

Table 4 SKOOP (Sfa Knee OsteOtomy Predictive) score

Parameters	0 point	1 point	2 points
Age	< 55 years	≥ 55 years	-
Body mass index	< 25	[25–34]	≥ 35
Articular narrowing	Incomplete	Complete	-

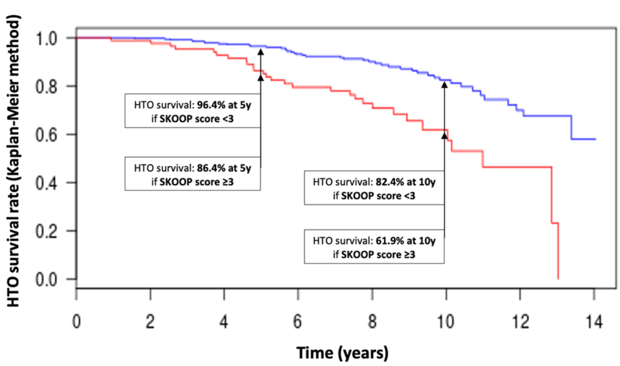

Fig. 2 HTO survival rate according to time (years) with a SKOOP score less than 3 (blue curve) versus HTO survival rate with a SKOOP score greater than or equal to 3 (red curve) compared by the log rank test ($p < 0.001$)

The HTO survival rate was 74% at 10 years. In the literature, the survival rates varied between 51 and 97% at 10 years, according to the studies [10, 19]. A study on a large database of 3195 knees reported similar statistics, with HTO survivorship rates of 89% at 5 years and 73% at 10 years [11]. This variation was mainly caused by the diversity of indications and surgical techniques. Indeed, the main cause of conversion to TKA in this study was the progression of osteoarthritis (lateral or even medial), as in other studies [4, 6, 7, 11, 19]. Borderline indications, such as a complete joint narrowing, for example, have a higher risk of early conversion to TKA. According to the surgeon's experience and practice, HTO would be an early treatment for an early stage of osteoarthritis or the last chance of conservative treatment in advanced osteoarthritis. According to the authors and the initial indications, the mean delay before HTO failure was also variable—between 9 months and 10 years in the literature [20]. The mean delay of conversion to TKA of 7 years in this study was similar to that in large studies with long-term follow-up [4, 5, 11, 21].

The predictive factors of clinical outcomes and HTO survival rate have been described in the literature. This study identified three types of predictive factors: preoperative variables, parameters during the surgery, and postoperative variables. Preoperatively, age, BMI, sex, and osteoarthritis severity were described as strong predictive factors of HTO survival. Several studies on registry data have reported a similarly high risk of revision to TKA with increasing age,

Table 5 Probability of HTO survival according to the SKOOP score

HTO survival rate	Score < 3 *N* = 326 HTO	Score ≥ 3 *N* = 85 HTO
Survival rate at 5 years	96.4% IC 95 [94.3–98.5]	86.4% IC 95 [79.2–94.2]
Survival rate at 7.5 years	91.2% IC 95 [87.8–94.8]	76.3% IC 95 [67.2–86.6]
Survival rate at 10 years	82.4% IC 95 [76.6–88.5]	61.9% IC 95 [49.7–76.9]

HTO high tibial osteotomy

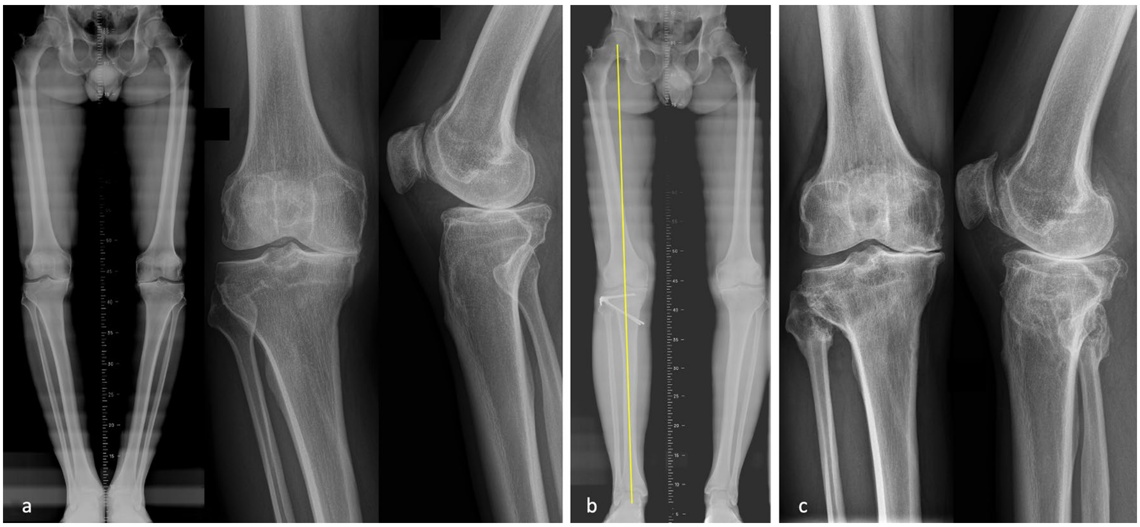

Fig. 3 A 52-year-old man (BMI: 22 kg/m2) complained of right knee pain on knee osteoarthritis (complete narrowing of the medial joint space) with varus bone deformity (HKA: 168°, MPTA: 83°): SKOOP score = 2 (**a**). A closing-wedge osteotomy has been performed (**b**). At 12 years of follow-up, the patient is satisfied, without significant knee pain, without surgical revision (**c**)

BMI, and female sex [4, 7, 11, 19]. Gstöttner et al. found a 5% increase in the conversion rate to TKA with every 1-year increase in the patient's age [8]. Hui et al. compared patients younger and older than 50 years and found a hazard ratio of 3.7 in patients older than 50 years [9]. Obesity both increases the osteoarthritis risk and affects the outcomes of surgery. Flecher et al. confirmed that increased BMI was associated with HTO survivorship with a threshold identified as a BMI of 30 kg/m^2, above which the failure risk would be significantly increased [7]. For other authors, the threshold value was 27.5 or 25.35 kg/m^2 [6, 19]. Several prior studies have demonstrated that increased severity of osteoarthritis leads to shorter HTO survival times [22]. A study by van Raaij et al. found 10-year survival rates of 90% in patients with Ahlbäck grade 1 compared with 62% in patients with Ahlbäck grade ≥ 2 [12]. Flecher et al. found that patients with Ahlbäck grade 1 or 2 had significantly lower failure rates with a hazard ratio of 0.29 [7]. Previous studies attempting to summarize prognostic factors for HTO have looked primarily at surgical factors such as angle of correction, operative technique, and rate of complications [15].

Among the studies assessing the risk factors for HTO revision, to our knowledge, no study has developed a predictive model or score to aid decision-making. Indeed, these risk factors were assessed independently and were not combined to precisely anticipate the risk of TKA conversion after HTO. Li et al. assessed combinations of risk factors for predicting conversion to TKA in patients with HTO surgery [6]. They reported that combining age, BMI, preoperative Kellgren Lawrence grade, and preoperative VAS (Visual Analog Scale) score had the highest value for predicting conversion to TKA in patients undergoing HTO surgery, with a sensitivity of 88.6% and specificity of 83.9%. Nevertheless, they did not determine the threshold values of these variables or an easily usable tool for clinical practice. Progressively with the development of machine learning in medicine, predictive models have been developed to help surgeons with decision-making. Several types of predictive models can be used in knee osteoarthritis: to determine if knee arthroplasty is recommended [23–25] or to predict certain outcomes, such as the risk of prosthetic joint infection or patient dissatisfaction post TKA [26–28]. Few predictive models have been established for HTO surgery [14, 15]. Spahn et al. determined a "predictive score" to anticipate poor results after HTO [15]. This score was based on a history greater than 2 years, a preoperative KOOS less than 50

Fig. 4 A 56-year-old woman (BMI: 36 kg/m2) complained of left knee pain on knee osteoarthritis (incomplete narrowing of the medial joint space) with varus bone deformity (HKA: 171°, MPTA: 79°): SKOOP score 3 (**a**). An opening wedge osteotomy has been performed. But after 4 years, the patient again had a very painful knee (**b**). A TKA has been necessary at 5 years post-osteotomy (**c**)

points, obesity, smoking, female sex, the presence of medial tibia exophytes, a joint space width less than 5 mm, and tibial defects of degree IV. Van Houten et al. reported a score to predict pseudoarthrosis risk [14]. The main risk factor was smoking, a risk factor not assessed in this study.

Several limitations should, however, be noted. First, this study was retrospective. The preoperative and perioperative factors were based on data in the medical records. Nevertheless, the studied factors were mainly demographic characteristics with no significant risk of error. Second, several surgical techniques were used. However, the surgical technique was not identified as a predictive factor of HTO survival. Then, the study was not conducted with a large sample size inclusive of data from multiple countries. Nevertheless, it was a multicentric study. The risk of bias related to the surgeon's experience was thus low.

The SKOOP score developed in this study allowed us to help in decision-making concerning medial femorotibial osteoarthritis. This score has the advantage of being easily calculated without complex or unknown data.

Conclusion

The SKOOP score, including age, BMI, and the presence or absence of complete joint line narrowing, can be a helpful decision aid in daily practice for HTO indications, particularly for borderline cases.

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Declarations

Conflict of interest Research support from Lepine. Consultant SBM, Medacta, Zimmer Biomet, Smith & Nephew, Amplitude, Corin, Acelity, NewClip Technics and Arthrex. Speaker for Serf. Royalties from X Nov and NewClip Technics.

Ethical approval All the procedures were performed in accordance with the ethical standards of the institutional and/or national research committee, the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the IDRCP review board under IRB n°2018-A-01353–52.

Informed consent All the patient participants provided informed consent for review of their medical records.

References

1. Yoon JR (2018) Some considerations in high tibial osteotomy. Knee Surg Relat Res 30(4):273–274. https://doi.org/10.5792/ksrr.18.066
2. Spahn G, Hofmann GO, von Engelhardt LV, Li M, Neubauer H, Klinger HM (2013) The impact of a high tibial valgus osteotomy and unicondylar medial arthroplasty on the treatment for knee osteoarthritis: a meta-analysis. Knee Surg Sports Traumatol Arthrosc 21(1):96–112. https://doi.org/10.1007/s00167-011-1751-2
3. Koh IJ, Kim MS, Sohn S, Song KY, Choi NY, Jung H et al (2019) Predictive factors for satisfaction after contemporary unicompartmental knee arthroplasty and high tibial osteotomy in isolated medial femorotibial osteoarthritis. Orthop Traumatol Surg Res 105(1):77–83. https://doi.org/10.1016/j.otsr.2018.11.001
4. Khoshbin A, Sheth U, Ogilvie-Harris D, Mahomed N, Jenkinson R, Gandhi R et al (2017) The effect of patient, provider and surgical factors on survivorship of high tibial osteotomy to total knee arthroplasty: a population-based study. Knee Surg Sports Traumatol Arthrosc 25(3):887–894. https://doi.org/10.1007/s00167-015-3849-4
5. Pannell WC, Heidari KS, Mayer EN, Zimmerman K, Heckmann N, McKnight B et al (2019) High tibial osteotomy survivorship: a population-based study. Orthop J Sports Med 7(12):2325967119890693. https://doi.org/10.1177/2325967119890693
6. Li HB, Nie S, Lan M, Tang ZM, Liao XG (2020) The risk factors for early conversion to total knee arthroplasty after high tibial osteotomy. Comput Methods Biomech Biomed Engin. https://doi.org/10.1080/10255842.2020.1849155
7. Flecher X, Parratte S, Aubaniac JM, Argenson JN (2006) A 12–28-year followup study of closing wedge high tibial osteotomy. Clin Orthop Relat Res. https://doi.org/10.1097/01.blo.0000229362.12244.f6
8. Gstottner M, Pedross F, Liebensteiner M, Bach C (2008) Long-term outcome after high tibial osteotomy. Arch Orthop Trauma Surg 128(1):111–115. https://doi.org/10.1007/s00402-007-0438-0
9. Hui C, Salmon LJ, Kok A, Williams HA, Hockers N, van der Tempel WM et al (2011) Long-term survival of high tibial osteotomy for medial compartment osteoarthritis of the knee. Am J Sports Med 39(1):64–70. https://doi.org/10.1177/0363546510377445
10. Naudie D, Bourne RB, Rorabeck CH, Bourne TJ (1999) The Install award. survivorship of the high tibial valgus osteotomy. A 10- to -22-year followup study. Clin Orthop Relat Res 367:18–27
11. Niinimaki TT, Eskelinen A, Mann BS, Junnila M, Ohtonen P, Leppilahti J (2012) Survivorship of high tibial osteotomy in the treatment of osteoarthritis of the knee: finnish registry-based study of 3195 knees. J Bone Joint Surg Br 94(11):1517–1521. https://doi.org/10.1302/0301-620X.94B11.29601
12. van Raaij T, Reijman M, Brouwer RW, Jakma TS, Verhaar JN (2008) Survival of closing-wedge high tibial osteotomy: good outcome in men with low-grade osteoarthritis after 10–16 years. Acta Orthop 79(2):230–234. https://doi.org/10.1080/17453670710015021
13. Park JY, Chang CB, Kang DW, Oh S, Kang SB, Lee MC (2019) Development and validation of a prediction model for knee joint line orientation after high tibial osteotomy. BMC Musculoskelet Disord 20(1):434. https://doi.org/10.1186/s12891-019-2820-9
14. van Houten AH, Heesterbeek PJ, van Heerwaarden RJ, van Tienen TG, Wymenga AB (2014) Medial open wedge high tibial osteotomy: can delayed or nonunion be predicted? Clin Orthop Relat Res 472(4):1217–1223. https://doi.org/10.1007/s11999-013-3383-y
15. Spahn G, Kirschbaum S, Kahl E (2006) Factors that influence high tibial osteotomy results in patients with medial gonarthritis: a score to predict the results. Osteoarthritis Cartilage 14(2):190–195. https://doi.org/10.1016/j.joca.2005.08.013
16. Saragaglia D, Roberts J (2005) Navigated osteotomies around the knee in 170 patients with osteoarthritis secondary to genu varum. Orthopedics 28(10 Suppl):s1269-1274. https://doi.org/10.3928/0147-7447-20051002-13
17. Cooke TD (2002) Definition of axial alignment of the lower extremity. J Bone Joint Surg Am 84(1):146–147. https://doi.org/10.2106/00004623-200201000-00027
18. Cooke TD, Scudamore RA, Bryant JT, Sorbie C, Siu D, Fisher B (1991) A quantitative approach to radiography of the lower limb. Principles and applications. J Bone Joint Surg Br 73(5):715–720. https://doi.org/10.1302/0301-620X.73B5.1894656
19. Akizuki S, Shibakawa A, Takizawa T, Yamazaki I, Horiuchi H (2008) The long-term outcome of high tibial osteotomy: a ten- to 20-year follow-up. J Bone Joint Surg Br 90(5):592–596. https://doi.org/10.1302/0301-620X.90B5.20386
20. Lee YS, Kim HJ, Mok SJ, Lee OS (2019) Similar outcome, but different surgical requirement in conversion total knee arthroplasty following high tibial osteotomy and unicompartmental knee arthroplasty: a meta-analysis. J Knee Surg 32(7):686–700. https://doi.org/10.1055/s-0038-1666999
21. Wd A, Robertsson O, Lohmander LS (2012) High tibial osteotomy in Sweden, 1998–2007: a population-based study of the use and rate of revision to knee arthroplasty. Acta Orthop 83(3):244–248. https://doi.org/10.3109/17453674.2012.688725
22. Efe T, Ahmed G, Heyse TJ, Boudriot U, Timmesfeld N, Fuchs-Winkelmann S et al (2011) Closing-wedge high tibial osteotomy: survival and risk factor analysis at long-term follow up. BMC Musculoskelet Disord. https://doi.org/10.1186/1471-2474-12-46
23. Bansback N, Trenaman L, MacDonald KV, Hawker G, Johnson JA, Stacey D et al (2019) An individualized patient-reported outcome measure (PROM) based patient decision aid and surgeon report for patients considering total knee arthroplasty: protocol for a pragmatic randomized controlled trial. BMC Musculoskelet Disord 20(1):89. https://doi.org/10.1186/s12891-019-2434-2
24. Jayakumar P, Bozic KJ (2020) Advanced decision-making using patient-reported outcome measures in total joint replacement. J Orthop Res 38(7):1414–1422. https://doi.org/10.1002/jor.24614
25. Jayakumar P, Moore MG, Furlough KA, Uhler LM, Andrawis JP, Koenig KM et al (2021) Comparison of an artificial intelligence-enabled patient decision aid vs educational material on decision

quality, shared decision-making, patient experience, and functional outcomes in adults with knee osteoarthritis: a randomized clinical trial. JAMA Netw Open 4(2):e2037107. https://doi.org/10.1001/jamanetworkopen.2020.37107
26. Twiggs JG, Wakelin EA, Fritsch BA, Liu DW, Solomon MI, Parker DA et al (2019) Clinical and statistical validation of a probabilistic prediction tool of total knee arthroplasty outcome. J Arthroplasty 34(11):2624–2631. https://doi.org/10.1016/j.arth.2019.06.007
27. Pua YH, Kang H, Thumboo J, Clark RA, Chew ES, Poon CL et al (2020) Machine learning methods are comparable to logistic regression techniques in predicting severe walking limitation following total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 28(10):3207–3216. https://doi.org/10.1007/s00167-019-05822-7
28. Kunze KN, Akram F, Fuller BC, Zabawa L, Sporer SM, Levine BR (2019) Internal validation of a predictive model for satisfaction after primary total knee arthroplasty. J Arthroplasty 34(4):663–670. https://doi.org/10.1016/j.arth.2018.12.020