

# ACL deficiency and varus osteoarthritis: high tibial osteotomy alone or combined with ACL reconstruction?

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## Abstract

**Introduction** This study investigates the mid- to long-term clinical and radiological outcome in patients with symptomatic varus osteoarthritis (OA) and deficiency of the anterior cruciate ligament (ACL) and analyzes whether there are differences between isolated high tibial osteotomy (HTO) or combined single-stage HTO and ACL reconstruction (ACLR).

**Methods** 26 patients who underwent HTO alone (group 1) and 26 patients who underwent single-stage HTO and ACLR (group 2) because of varus OA and ACL deficiency were examined at a mean of 5.8 years (SD 3.6 years) post-operatively. Assessment at follow-up (FU) was performed using a questionnaire including clinical scores (Lysholm, IKDC) and the KT-2000 arthrometer to examine anterior knee stability. Radiographic knee alignment and signs of OA according to the classification of Kellgren and Lawrence (KL) were assessed pre-operatively and at FU.

**Results** Eighty-one percent of all patients reported an improvement of pain and 79% an improvement of instability without significant group difference. Significant worse results were observed in group 1 for the Lysholm score (group 1: 69.4, SD 15.7; group 2: 78.3, SD 16.4;

$p = 0.020$ ) and the IKDC score (group 1: 64.8, SD 13.0; group 2: 74.0, SD 15.6;  $p = 0.006$ ). No group difference was found for the KT-2000 examination. A significant post-operative increase of radiographic OA could be seen in both groups without significant group difference (KL pre-operative: 2.3, SD 0.63; KL FU: 2.8, SD 0.74;  $p < 0.001$ ). The radiographic leg alignment at FU showed a significant lower valgus alignment in group 1 (group 1: 0.4 degree, SD 3.3 degree; group 2: 2.1 degree, SD 2.1 degree;  $p = 0.039$ ). The rate of post-operative complications was low with 4%, and no significant group differences were found.

**Conclusions** This study shows that HTO alone can improve pain and even subjective knee stability. Additional ACLR was in the mid term not associated with a higher increase of OA or a higher rate of post-operative complications in our study collective.

**Keywords** Knee · Varus · Osteoarthritis · HTO · Anterior instability · ACL reconstruction

## Introduction

Valgus producing high tibial osteotomy (HTO) is a widely accepted treatment option for relatively young and active patients with painful varus osteoarthritis of the knee joint [1, 6, 16, 23, 25, 42]. Similarly, anterior cruciate ligament reconstruction (ACLR) is a routine surgical procedure to restore knee stability in active patients after acute ACL injuries or in patients with chronic anterior knee instability [2, 7, 26, 28, 32, 43].

It is widely accepted that the event of an ACL injury is a significant risk factor for the early onset of knee osteoarthritis (OA), especially in varus angulated knees

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[22, 44]. However, the prevention of OA due to ACL reconstruction is still discussed controversial [5, 9, 14]. Dejour et al. even assumed a negative effect of ACLR on the development of OA, especially in pre-arthritis knee joints [19]. The previous studies have shown that varus alignment might have a negative influence on the outcome after ACLR due to an increased ligament strain [46, 48]. For this reason, combined HTO and ACLR is commonly recommended in ACL deficient and varus angulated knees without progressed cartilage degeneration. However, no consensus exists on the ideal treatment modality for patients with chronic ACL deficiency and symptomatic varus OA [3, 12, 13, 15, 40]. Whereas some authors recommend a staged procedure with an isolated HTO first and subsequent ACLR only in the case of persistent instability [29, 36, 37], other authors prefer a single-stage procedure with combined HTO and ACLR [3, 8, 10, 11, 30]. A single-stage procedure avoids a second operation and consecutively a second rehabilitation period, however, combined HTO and ACLR is technically demanding and may be associated with a higher rate of intra- and post-operative complications [3, 8, 10, 11, 17, 30, 35, 38, 47].

To date, only few studies have compared isolated HTO with single-stage HTO and ACLR in patients with anterior knee instability and symptomatic varus OA [8, 29, 37, 47]. These studies have recently been included in a systematic review on the clinical outcome after unicompartamental knee arthroplasty (UKA) and HTO in ACL deficiency [34]. However, due to the small study populations [8, 29] and short-term follow-up periods [37, 47], only limited conclusion could be made.

The aim of this study was, therefore, to report and to compare the mid- to long-term clinical and radiological results of isolated HTO vs. HTO + ACLR in a relatively large cohort of patients with pre-operative symptomatic varus OA and ACL deficiency.

## Materials and methods

The study population consisted of patients who underwent isolated HTO or single-stage HTO combined with ACLR because of symptomatic varus OA and ACL deficiency at one of the authors (A.B.I.) institution between 10/1996 and 09/2007.

The detailed inclusion criteria for this study were: symptomatic varus OA (defined as medial-sided knee pain), radiographic OA of the medial compartment  $\geq$  grade 1 according to Kellgren and Lawrence, varus alignment  $>0^\circ$  (as measured on full leg standing radiographs), arthroscopically verified ACL deficiency, age  $<50$  years, and follow-up period of at least 24 months. Exclusion criteria were additional ligament reconstruction other than

ACLR, pre-operative patellofemoral problems, and inflammatory rheumatic disease. Fifty-three patients met the above-mentioned criteria and could be included in this study. Twenty-seven patients (51%) were treated with an isolated HTO (group 1) and twenty-six patients (49%) were treated with single-stage HTO and ACLR (group 2).

A lateral closed-wedge HTO was performed in 25 cases (47%), while a medial open-wedge HTO was performed in 28 cases (53%). For ACLR, bone patellar tendon bone (BPTB) autografts were used in 14 cases (54%), BPTB allografts in three cases (12%), and hamstring tendon autografts in nine cases (35%). The corrected alignment of the leg was controlled radiologically at the end of the operation, whereas a slight overcorrection in valgus was aimed at in each case. The operative techniques have been described in detail elsewhere [27].

One patient of group 1 was revised to a total knee arthroplasty (TKA) during the follow-up period and was subsequently assessed as failure and excluded from further examination. The clinical outcome of the remaining 52 patients was evaluated retrospectively after a mean follow-up of 5.8 years (SD 3.6 years). Patients were asked about post-operative satisfaction and about the development of instability and pain of the operated knee joint. The Lysholm score and IKDC score were used as standardized outcome measures to evaluate the function of the operated knee. Anterior tibial translation of the affected knee in comparison to the non-affected contralateral knee was measured using the KT-2000 arthrometer, and the difference between both knees was given as final result. The post-operative alignment of the affected extremity and signs of OA according to the classification of Kellgren and Lawrence (KL) were assessed radiographically at final follow-up and compared with pre-operative images. Both the pre-operative and follow-up radiographs had been evaluated by three different observers and the average values were given as final results.

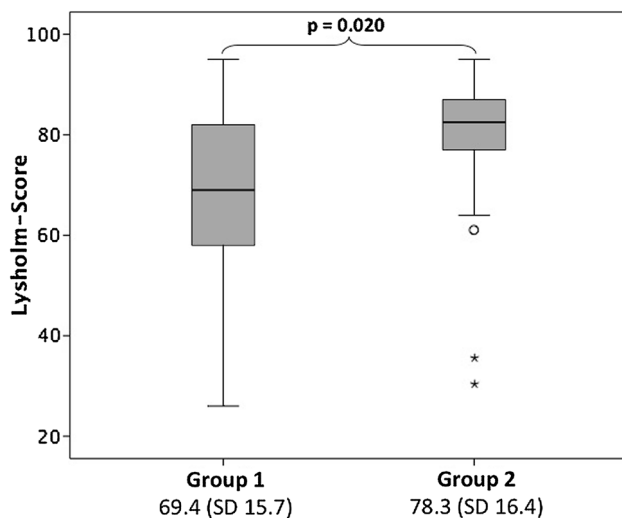
Statistical analysis was performed using IBM SPSS Statistics (version 19). Group comparison was performed using the Student's *t* test for normally distributed data and the Mann–Whitney test for not normally distributed data. The level of significance was set at  $p \leq 0.05$ .

## Results

Epidemiologic and pre-operative data of the two study groups are given in Table 1. At the time of surgery, patients of group 1 were significantly older and the pre-operative radiographs showed a significantly higher grade of OA. In addition, the follow-up time was significantly shorter in group 1.

**Table 1** Epidemiologic and pre-operative data of the two study groups

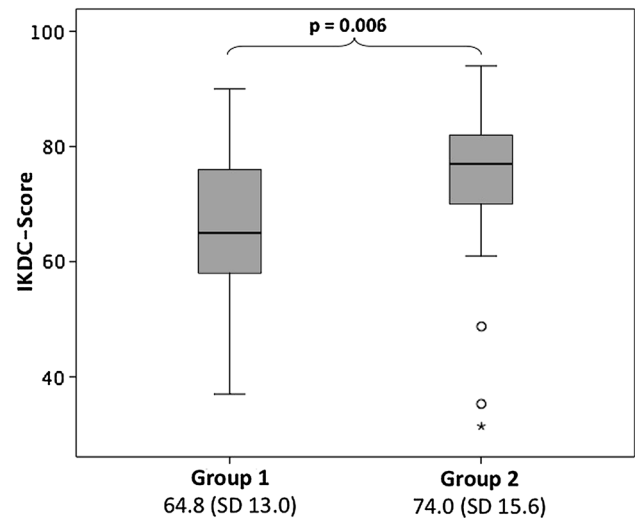
	Group 1	Group 2
Number of patients	26	26
Female/male	9/17	7/19
Age at surgery (years)*	40.5 (SD 6.4)	35.4 (SD 7.2)
BMI at surgery (kg/m <sup>2</sup> )	27.7 (SD 4.6)	25.8 (SD 3.4)
Pre-operative Kellgren–Lawrence grading**	2.7 (SD 0.62)	1.9 (SD 0.38)
Pre-operative varus angle (°)	6.0 (SD 3.1)	5.1 (SD 2.2)
Follow-up period (years)***	4.0 (SD 2.1)	7.7 (SD 3.8)

\* Significant difference ( $p = 0.013$ )\*\* Significant difference ( $p < 0.001$ )\*\*\* Significant difference ( $p = 0.005$ )**Fig. 1** Lysholm score at final follow-up. Group results given as mean and SD and presented in *box plots*. Significant group difference ( $p = 0.020$ )

At final follow-up, 48 patients (92%) were “very satisfied” or “satisfied” with the post-operative outcome and would undergo the same operative procedure again, while 3 patients (6%) were “moderately satisfied” and 1 patient (2%) was “unsatisfied” with the post-operative outcome and would not undergo the same operation again. There was no significant difference between the two groups according to post-operative satisfaction.

In comparison to the status before surgery, an improvement of pain was reported by 81% of all patients (group 1: 89%; group 2: 73%), and an improvement of subjective knee stability was reported by 79% of all patients (group 1: 77%; group 2: 81%) without significant group differences for both values.

The analysis of the clinical scores showed a mean Lysholm score of 73.9 (SD 16.5) and a mean IKDC score of 69.4 (SD 15.0) for all patients. Group 1 showed a significantly worse result in the Lysholm score and in the

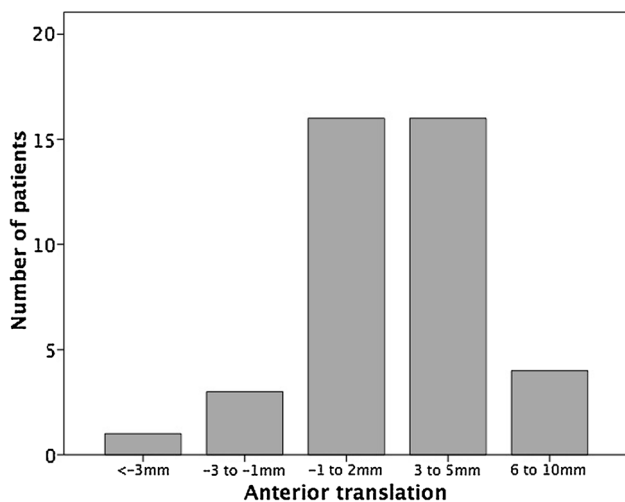
**Fig. 2** IKDC score at final follow-up. Group results given as mean and SD and presented in *box plots*. Significant group difference ( $p = 0.006$ )

IKDC score compared to group 2. The results of the clinical scores are presented in Figs. 1 and 2.

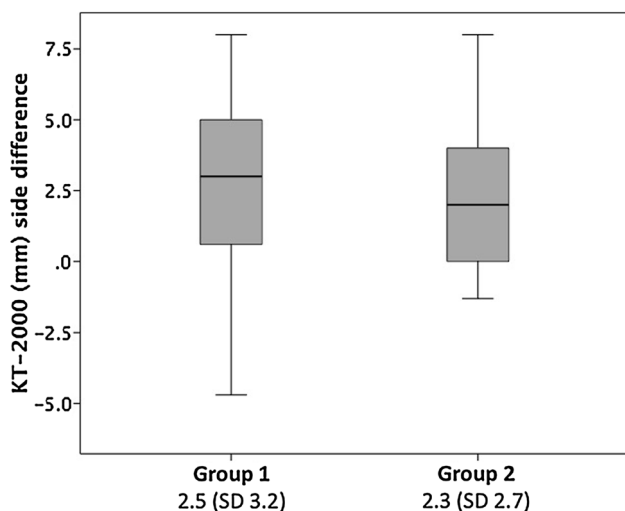
The evaluation of anterior knee instability using the KT-2000 arthrometer showed mostly good and fair results for all patients (Fig. 3) with no significant difference between both groups (Fig. 4).

The comparison of pre-operative and follow-up radiographs showed a significant increase of radiological OA signs in both study groups. The mean KL grading of all patients significantly increased from 2.3 (SD 0.63) pre-operatively to 2.8 (SD 0.74) at final follow-up ( $p < 0.001$ ). There was no significant difference in OA progression between the two study groups (Fig. 5).

The radiographic analysis of the post-operative alignment showed a mean mechanical axis of 181.2° (SD 2.9°), indicating a slight valgus of 1.2°. There was a significantly lower valgus alignment in group 1 in comparison to group 2 ( $p = 0.039$ ) (Fig. 6).



**Fig. 3** Results of KT-2000 measurement at final follow-up for all patients. Side difference of anterior tibial translation of the operated knee in comparison to the healthy contralateral knee given in millimeter

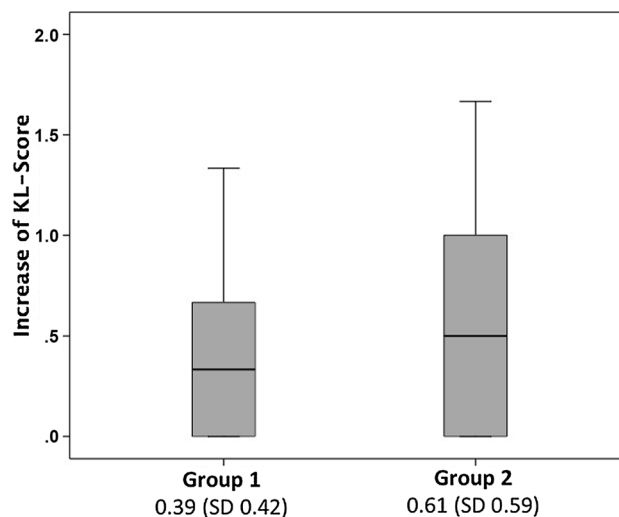


**Fig. 4** KT-2000 measurement in mm side difference at final follow-up: group results given as mean and SD and presented in *box plots*. No significant group difference

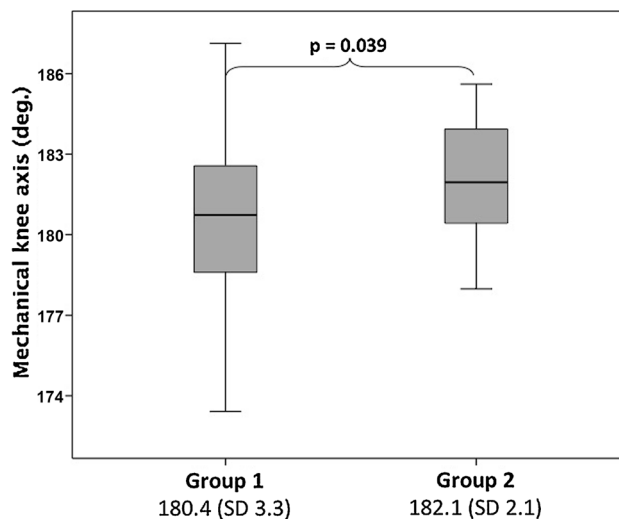
During the follow-up period, a total of 5 patients (9.6 percent) required further surgeries at the affected knee in addition to the elective removal of the osteotomy plate (Table 2).

## Discussion

The most important finding of this study was that both major symptoms, pain and instability, could be improved on a long-term basis in the vast majority of all cases leading to a high rate of post-operative satisfaction independent of the surgical procedure.



**Fig. 5** Increase of KL score from pre-operative to final follow-up: group results given as mean and SD and presented in *box plots*. No significant group difference



**Fig. 6** Mechanical knee axis at final follow-up: 180 degree indicating a straight axis, >180 degree indicating varus, and <180 degree indicating valgus. Group results given as mean and SD and presented in *box plots*. Significant group difference ( $p = 0.039$ )

Patients with symptomatic varus OA and ACL deficiency are a heterogeneous group, which is one reason why there are no clear recommendations in the literature on how these patients should be treated. In the past few years, a trend could be seen towards a combined procedure of valgus HTO and ACLR, especially in younger active patients, while HTO alone was preferred in older patients with advanced OA [3, 8, 10, 47]. This trend has also been considered in the treatment of our study population, as indicated by a significantly higher age and a significantly higher grade of OA at time of surgery in group 1. This selection bias certainly makes the group comparison more

**Table 2** Operative procedures at the relevant knee joint since primary surgery

Group	Patient	Procedure
Group 1	No. 1	2 × wound revision after plate removal
	No. 2	Arthroscopy, microfracturing
	No. 3	3 × wound revision due to infection
Group 2	No. 1	Arthroscopy, partial medial meniscectomy, POL release, cyclops resection
	No. 2	Arthroscopy, partial medial meniscectomy

difficult; nevertheless, relevant findings could still be revealed by this study.

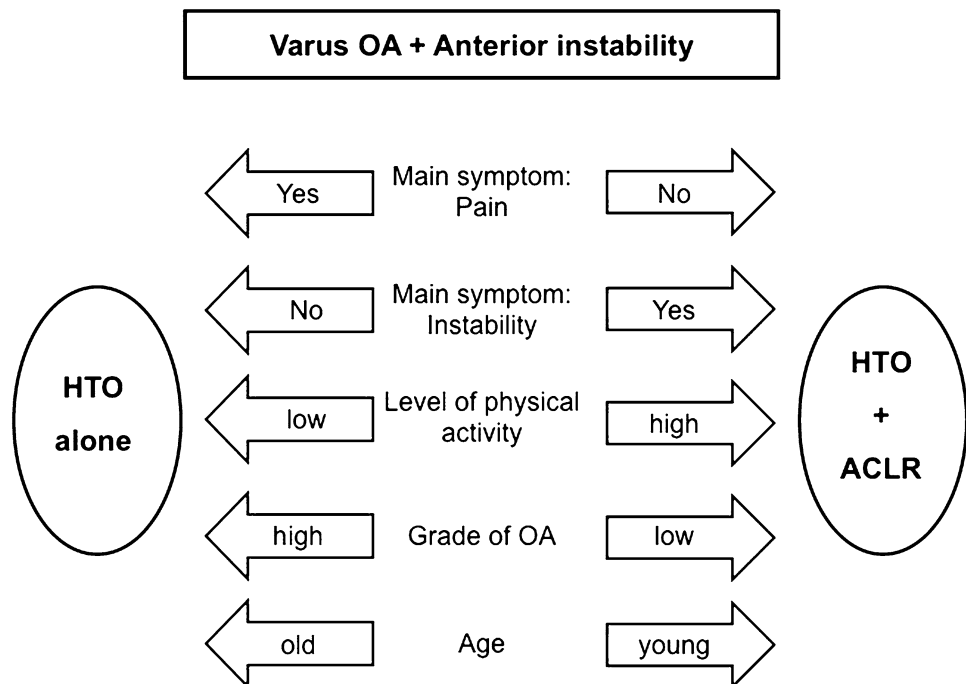
The evaluation of the clinical scores showed mostly satisfying results in both study groups. Since the Lysholm score is a sensitive measure for instability related problems, the significantly worse results for the patients of group 1 compared with patients who had additionally been treated with ACLR, could be expected. This, however, does not indicate that there was no gain of stability in group 1 as the vast majority of these patients (77%) reported an improvement of subjective knee stability in the post-operative course. In comparison with the Lysholm score, the IKDC score is rather focused on arthrosis-related symptoms. Although an improvement of pain was reported by almost 90% of group 1, they showed significantly worse results in the IKDC score in comparison to group 2. These results are even more enhanced considering the patient of group 1, who was revised to a TKA and, therefore, has to be evaluated as failure. The worse results of group 1 may be caused by the fact that these patients already had a higher grade of OA at time of surgery. In addition to that, the significant lower valgus alignment at FU in group 1 represents a relevant risk factor for worse clinical results in patients, who suffer from medial gonarthrosis.

Since several previous long-term studies have already shown that HTO is a suitable procedure to reduce pain in patients with varus OA [1, 6, 16, 25, 42], the significant relief of pain in most of our patients was not surprising. Likewise, an improvement of pain and instability could be seen in this study after combined HTO and ACLR, as demonstrated by several studies before [3, 8, 10, 11, 31, 36, 37, 45, 47]. However, the fact that HTO without ACLR has led to a significant improvement of subjective knee stability in patients with varus OA and ACL deficiency is rather surprising. Nevertheless, this finding is not completely new, since few previous studies have already shown this correlation [18, 29, 37, 47]. Williams et al., for example, described an improvement of subjective knee stability in 67% of patients after isolated HTO [47]. Different reasons for this observation have been suggested. Dejour et al. interpret the gain of stability as a consequence of the modified biomechanics in the arthritic knee joint with increased development of osteophytes, which lead to a widening of the articular surface and,

therefore, to an increase of stability especially under axial loads [18]. Since group 1 showed a significantly higher grade of OA, this explanation seems quite suitable for our study as well. Another aspect that might influence knee stability after HTO is a modification of the tibial slope. Several mathematical and cadaver studies have shown an increase of anterior tibial translation in correlation with the tibial slope [4, 20, 24, 33, 39, 41]. A higher strain on the ACL by increasing the tibial slope, however, could not be demonstrated which seems to be caused by the fact that an increased slope does not only lead to an anterior translation of the tibia but also to a superior translation and an external rotation of the tibia leading to an approximation of the ACL origins and, therefore, to a decrease of ACL strain [4, 21]. It, therefore, remains unclear whether changes of the tibial slope influence knee stability in ACL deficient knees. In accordance to recommendations of recent studies, open-wedge osteotomy had consistently been emphasized in the posterior aspect in our patients to avoid an increase of the tibial slope [21]. However, an appropriate statement on a possible change of the tibial slope and consecutively on its influence on knee stability could retrospectively not be done on the basis of present data. Nevertheless, the results of our study show that HTO without ACLR is a reasonable procedure in patients with intermediate-stage medial OA and anterior instability, not only to reduce pain, but also to improve knee stability. This statement is even more verified due to the fact that the objective evaluation of anterior knee stability with the KT-2000 arthrometer did not show significant worse results in patients who had been treated with HTO alone in comparison to the patients who had additional ACLR.

A further important finding of this study was that a significant increase of radiological OA could be detected in both study groups. In accordance with the previous studies [29, 47], the progression of OA could not be stopped in most cases. However, only one of the 53 included patients had to be converted to total knee arthroplasty, and therefore, the operative procedures performed in this study seem to be capable of slowing down the degeneration of the knee joint also on a long-term basis. Furthermore, additional ACLR had no influence on the rate of OA progression. It can, therefore, be argued that a combined HTO and ACLR is also a reasonable option in older patients with higher

**Fig. 7** Important parameters that should be considered in the process of decision-making with regard to the operative procedure in patients with varus OA and anterior knee instability



grades of OA, especially when suffering from both, pain and instability.

The results of the radiological assessment of the knee axis at final follow-up led to the assumption that some patients had undergone a loss of correction during the post-operative course. This phenomenon was already described by Noyes et al. who observed a correlation between the loss of correction and the time, since HTO caused by a gradual decompensation of the medial joint surface in the osteoarthritic knee [36]. This would also explain the results in group 1 with a greater loss of correction due to the higher grade of OA at the time of surgery. An important finding in this connection is the fact that an additional ACLR does not seem to have a negative influence on an increased loss of correction, quite in contrary, it seems conceivable that additional ACLR may counteract this development.

Compared to isolated HTO, a higher complication rate has been reported after concomitant ACLR, especially in older publications [29, 36, 37]. Specifically, a higher risk of overcorrection, rapid loss of correction, material loosening, infection, and re-rupture of the ACL have been described by these authors. In our study, however, there was no patient with significant overcorrection, rapid loss of correction, material loosening, or re-rupture of the ACL. No patient who had been treated by a combined procedure needed wound revision because of infection, while two patients of group 1 needed wound revision. Accordingly, the results of this study do not confirm a higher complication rate after combined HTO and ACLR compared to isolated HTO.

Along with certain strengths, there are some limitations of this study. As already described, the whole study group is quite heterogeneous and the patients had been treated according to recommendations of current studies at the time of operation which led to a selection bias and, therefore, to a decrease of statistical significance regarding the group comparison. To reduce this bias, an age limit of 50 years was set as inclusion criteria, but still a remaining bias had been accepted to keep the study group as large as possible. Further limitations are the lack of pre-operative values of the clinical scores (Lysholm and IKDC) and of pre-operative values of the KT-2000 measurement which is why a statement on the development of these values in the post-operative course could not be made. Nevertheless, to acquire information about the post-operative course, the patients had been asked about the development of the main symptoms pain and instability at follow-up. Furthermore, a prospective radiographic analysis was performed comparing the pre-operative images with the images made at follow-up to gain information of the development of OA.

In summary, patients with symptomatic varus OA in combination with anterior knee instability are still a challenge for orthopedic surgeons, especially since these patients represent a very heterogeneous group with widely differing symptoms, complaints, and expectations. Therefore, a “one fits all therapy” is certainly not realistic, but a differentiated approach considering the patients’ main symptoms pain and instability, the level of activity, the grade of OA, and the patients’ age is necessary to achieve a high post-operative satisfaction (Fig. 7). For the process of

decision-making, it should be considered that a reasonable improvement of knee stability can be achieved also by HTO alone; however, in patients with relevant knee instability and high demands on physical activity, the indication for combined HTO and ACLR should be considered.

## Conclusion

In patients with symptomatic varus OA and anterior knee instability, HTO alone is an appropriate method to improve pain symptoms even in a long-term basis. To a certain extent, also the knee stability can be improved by this single procedure. This study shows that additional one-staged reconstruction of the ACL, however, seems to even improve knee function without significant risk of increased OA progression or increased complication rate in a mid-term perspective.

## Compliance with ethical standards

The authors declare that they have no conflict of interest. This study was approved by the internal review board and written informed consent was provided by all patients prior to inclusion.

## References

1. Aglietti P, Buzzi R, Vena LM, Baldini A, Mondaini A (2003) High tibial valgus osteotomy for medial gonarthrosis: a 10- to 21-year study. *J Knee Surg* 16(1):21–26
2. Aglietti P, Buzzi R, Zaccherotti G, De Biase P (1994) Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med* 22(2):211–217
3. Agneskirchner JD, Burkart A, Imhoff AB (2002) Achsenfehlstellung, Knorpelschaden und Kreuzbandruptur–Begleiteingriffe bei der VKB-Plastik. *Unfallchirurg* 105(3):237–245
4. Agneskirchner JD, Hurschler C, Stukenborg-Colsman C, Imhoff AB, Lobenhoffer P (2004) Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Winner of the AGA-DonJoy Award 2004. *Arch Orthop Trauma Surg* 124(9):575–584
5. Ajuied A, Wong F, Smith C, Norris M, Earnshaw P, Back D, Davies A (2014) Anterior cruciate ligament injury and radiologic progression of knee osteoarthritis: a systematic review and meta-analysis. *Am J Sports Med* 42(9):2242–2252
6. 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 Jt Surg Br* 90(5):592–596
7. Almqvist KF, Willaert P, De Brabandere S, Criel K, Verdonk R (2009) A long-term study of anterior cruciate ligament allograft reconstruction. *Knee Surg Sports Traumatol Arthrosc* 17(7):818–822
8. Badhe NP, Forster IW (2002) High tibial osteotomy in knee instability: the rationale of treatment and early results. *Knee Surg Sports Traumatol Arthrosc* 10(1):38–43
9. Barenius B, Ponzer S, Shalabi A, Bujak R, Norlen L, Eriksson K (2014) Increased risk of osteoarthritis after anterior cruciate ligament reconstruction: a 14-year follow-up study of a randomized controlled trial. *Am J Sports Med* 42(5):1049–1057
10. Bonin N, Ait Si Selmi T, Donell ST, Dejour H, Neyret P (2004) Anterior cruciate reconstruction combined with valgus upper tibial osteotomy: 12 years follow-up. *Knee* 11(6):431–437
11. Boss A, Stutz G, Oursin C, Gächter A (1995) Anterior cruciate ligament reconstruction combined with valgus tibial osteotomy (combined procedure). *Knee Surg Sports Traumatol Arthrosc* 3(3):187–191
12. Bruns J, Volkmer M, Luessenhop S (1993) Pressure distribution at the knee joint. Influence of varus and valgus deviation without and with ligament dissection. *Arch Orthop Trauma Surg* 113(1):12–19
13. Cerejo R, Dunlop DD, Cahue S, Channin D, Song J, Sharma L (2002) The influence of alignment on risk of knee osteoarthritis progression according to baseline stage of disease. *Arthritis Rheum* 46(10):2632–2636
14. Chalmers PN, Mall NA, Moric M, Sherman SL, Paletta GP, Cole BJ, Bach Jr BR (2014) Does ACL reconstruction alter natural history?: A systematic literature review of long-term outcomes. *J Bone Jt Surg Am* 96(4):292–300
15. Cicuttini F, Wluka A, Hankin J, Wang Y (2004) Longitudinal study of the relationship between knee angle and tibiofemoral cartilage volume in subjects with knee osteoarthritis. *Rheumatology (Oxford)* 43(3):321–324
16. Coventry MB, Ilstrup DM, Wallrichs SL (1993) Proximal tibial osteotomy. A critical long-term study of eighty-seven cases. *J Bone Jt Surg Am* 75(2):196–201
17. Dejour H, Neyret P, Boileau P, Donell ST (1994) Anterior cruciate reconstruction combined with valgus tibial osteotomy. *Clin Orthop Relat Res* 299:220–228
18. Dejour H, Neyret P, Bonnin M, Fu F, Harner C (1994) Instability and osteoarthritis. *Knee Surg* 42:859–875
19. Dejour H, Walch G, Deschamps G, Chambat P (2014) Arthrosis of the knee in chronic anterior laxity. *Orthop Traumatol Surg Res* 100(1):49–58
20. Fening SD, Kovacic J, Kambic H, McLean S, Scott J, Miniaci A (2008) The effects of modified posterior tibial slope on anterior cruciate ligament strain and knee kinematics: a human cadaveric study. *J Knee Surg* 21(3):205–211
21. Feucht MJ, Mauro CS, Brucker P, Imhoff AB, Hinterwimmer S (2013) The role of the tibial slope in sustaining and treating anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc* 21(1):134–145
22. Friel NA, Chu CR (2013) The role of ACL injury in the development of posttraumatic knee osteoarthritis. *Clin Sports Med* 32(1):1–12
23. Fujisawa Y, Masuhara K, Shiomi S (1979) The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. *Orthop Clin N Am* 10(3):585–608
24. Griffin JR, Vogrin TM, Zantop T, Woo SL, Harner CD (2004) Effects of increasing tibial slope on the biomechanics of the knee. *Am J Sports Med* 32(2):376–382
25. Hernigou P, Medevielle D, Debeyre J, Goutallier D (1987) Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. *J Bone Jt Surg Am* 69(3):332–354
26. Hertel P, Behrend H, Cierpinski T, Musahl V, Widjaja G (2005) ACL reconstruction using bone-patellar tendon-bone press-fit fixation: 10-year clinical results. *Knee Surg Sports Traumatol Arthrosc* 13(4):248–255
27. Hinterwimmer S, Mehl J (2014) Combination of ACL-replacement and high tibial osteotomy. *Oper Orthop Traumatol* 26(1):43–55
28. Johnson RJ, Eriksson E, Haggmark T, Pope MH (1984) Five- to ten-year follow-up evaluation after reconstruction of the anterior cruciate ligament. *Clin Orthop Relat Res* 183:122–140

29. Lattermann C, Jakob RP (1996) High tibial osteotomy alone or combined with ligament reconstruction in anterior cruciate ligament-deficient knees. *Knee Surg Sports Traumatol Arthrosc* 4(1):32–38
30. Lerat JL, Moyon B, Garin C, Mandrino A, Besse JL, Brunet-Guedj E (1993) Anterior laxity and internal arthritis of the knee. Results of the reconstruction of the anterior cruciate ligament associated with tibial osteotomy. *Rev Chir Orthop Repar Appar Mot* 79(5):365–374
31. Li Y, Zhang H, Zhang J, Li X, Song G, Feng H (2015) Clinical outcome of simultaneous high tibial osteotomy and anterior cruciate ligament reconstruction for medial compartment osteoarthritis in young patients with anterior cruciate ligament-deficient knees: a systematic review. *Arthroscopy* 31(3):507–519
32. Liden M, Ejerhed L, Sernert N, Laxdal G, Kartus J (2007) Patellar Tendon or Semitendinosus Tendon Autografts for Anterior Cruciate Ligament Reconstruction: A Prospective, Randomized Study with a 7-Year Follow-up. *Am J Sports Med* 35(5):740–748
33. Liu W, Maitland ME (2003) Influence of anthropometric and mechanical variations on functional instability in the ACL-deficient knee. *Ann Biomed Eng* 31(10):1153–1161
34. Mancuso F, Hamilton TW, Kumar V, Murray DW, Pandit H (2016) Clinical outcome after UKA and HTO in ACL deficiency: a systematic review. *Knee Surg Sports Traumatol Arthrosc* 24(1):112–122
35. Neuschwander DC, Drez Jr D, Paine RM (1993) Simultaneous high tibial osteotomy and ACL reconstruction for combined genu varum and symptomatic ACL tear. *Orthopedics* 16(6):679–684
36. Noyes FR, Barber-Westin SD, Hewett TE (2000) High tibial osteotomy and ligament reconstruction for varus angulated anterior cruciate ligament-deficient knees. *Am J Sports Med* 28(3):282–296
37. Noyes FR, Barber SD, Simon R (1993) High tibial osteotomy and ligament reconstruction in varus angulated, anterior cruciate ligament-deficient knees. A two- to seven-year follow-up study. *Am J Sports Med* 21(1):2–12
38. O'Neill DF, James SL (1992) Valgus osteotomy with anterior cruciate ligament laxity. *Clin Orthop Relat Res* 278:153–159
39. Shao Q, MacLeod TD, Manal K, Buchanan TS (2011) Estimation of ligament loading and anterior tibial translation in healthy and ACL-deficient knees during gait and the influence of increasing tibial slope using EMG-driven approach. *Ann Biomed Eng* 39(1):110–121
40. Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD (2001) The role of knee alignment in disease progression and functional decline in knee osteoarthritis. *JAMA* 286(2):188–195
41. Shelburne KB, Kim HJ, Sterett WI, Pandy MG (2011) Effect of posterior tibial slope on knee biomechanics during functional activity. *J Orthop Res* 29(2):223–231
42. Sprenger TR, Doerzbacher JF (2003) Tibial osteotomy for the treatment of varus gonarthrosis. Survival and failure analysis to twenty-two years. *J Bone Jt Surg Am* 85-A(3):469–474
43. Strand T, Molster A, Hordvik M, Krukhaug Y (2005) Long-term follow-up after primary repair of the anterior cruciate ligament: clinical and radiological evaluation 15–23 years postoperatively. *Arch Orthop Trauma Surg* 125(4):217–221
44. Sward P, Friden T, Boegard T, Kostogiannis I, Neuman P, Roos H (2013) Association between varus alignment and post-traumatic osteoarthritis after anterior cruciate ligament injury. *Knee Surg Sports Traumatol Arthrosc* 21(9):2040–2047
45. Trojani C, Elhor H, Carles M, Boileau P (2014) Anterior cruciate ligament reconstruction combined with valgus high tibial osteotomy allows return to sports. *Orthop Traumatol Surg Res* 100(2):209–212
46. van de Pol GJ, Arnold MP, Verdonchot N, van Kampen A (2009) Varus alignment leads to increased forces in the anterior cruciate ligament. *Am J Sports Med* 37(3):481–487
47. Williams III RJ, Kelly BT, Wickiewicz TL, Altchek DW, Warren RF (2003) The short-term outcome of surgical treatment for painful varus arthritis in association with chronic ACL deficiency. *J Knee Surg* 16(1):9–16
48. Zaffagnini S, Bonanzinga T, Grassi A, Muccioli GM, Musiani C, Raggi F, Iacono F, Vaccari V, Marcacci M (2013) Combined ACL reconstruction and closing-wedge HTO for varus angulated ACL-deficient knees. *Knee Surg Sports Traumatol Arthrosc* 21(4):934–941