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Gait analysis and knee kinematics before, and 6 and 18 months after corrective valgus osteotomy

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ABSTRACT

Background: The study objective was to assess clinical outcomes and gait biomechanics in patients after 6 and 18 months after varus deformity (VD) surgical correction at knee joint (KJ).
Method: The study included 20 patients with medial osteoarthritis (OA) of the knee of grade 2–3 and a VD of >4°. A total of 21 surgeries were performed on the patients. Full length weight bearing (FLWB) X-ray and KJ assessments were done using the KSS, KOOS and VAS scoring systems were obtained from all the patients. Biomechanical gait parameters were captured using an inertial sensor system at timepoints before, and 6 and 18 months after surgery. Temporal and kinematic parameters of walking were analyzed.
Results: The radiological parameters showed a stable VD correction. According to the KOOS, KS and VAS scores, there was a moderate dynamic improvement in the operated knee function during the study. The biomechanical parameters remained virtually unchanged throughout the entire follow-up period. In the following year, there were some subjective improvements but without any significant changes in gait biomechanics or knee kinematics.
Conclusions: Thus, the main changes in the joint clinical condition and function occur in the first 6 months after surgery. According to the study data—assessments by VAS, KOOS, and KSS—there was a moderate clinical improvement during the long-term follow-up period, however, the biomechanical changes were minor.

1. Introduction

Osteoarthritis (OA) of the medial knee compartment is a common consequence of a varus deformity of the lower limb [1,2]. Varus deformity changes not only the knee loading, but also the biomechanics of the joint [3].

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Corrective knee osteotomy is used as a joint-preserving surgery for varus deformity [4,5]. One of the ways to correct such deformities is by open wedge high tibial osteotomy (OWHTO). The main objective of corrective osteotomy is to relieve the stress on the affected medial part of the joint by correcting the limb axis towards valgus, thereby restoring normal biomechanics of the joint [6–8]. Elimination of excessive medial knee loading reduces the pain syndrome and slows down OA progression [9].

There is an important issue of changes in knee biomechanics due to varus deformity, as well as after OWHTO. Some authors report the absence of significant changes in gait parameters at 12 months after surgery, although they note improvement in patients' subjective assessment of their walking function by the KOOS, WOMAC and Lysholm scores [10]. Others report normalization of some parameters at 12 months after surgery. These include: walking speed, stride length, knee flexion amplitude and knee flexion moment. The varus angle and the adduction moment of the operated knee also decrease [11,12]. According to Liu [13], WOHTO improves walking speed, stride length, knee range of motion, and knee adduction moment.

A study by Bode [14] showed positive functional results 5 years after surgical treatment. According to Da Silva [15], knee pain, maximum flexion amplitude, walking speed and knee adduction moment after OWHTO are the key indicators of its effectiveness. A study by Da Cunha [16] in subjects with bilateral VD showed improved walking biomechanics after OWHTO. In particular, the knee torque in the frontal plain decreased. Our previous study [17] showed some significant changes in gait biomechanics and affected knee kinematics within 6 months after OWHTO. At the same time, as noted by Liu [13], there is not enough information about changes in the KJ biomechanics caused by osteoarthritis and the following surgical treatment.

The study objective was to assess longer-term functional, clinical, X-ray outcomes and gait biomechanics in patients after OWHTO at 6 and 18 months post-surgery.

The main hypothesis of the study is that basic functional changes occur in the first six months after OWHTO. During the following 12 months, the joint function and walking improve further.

2. Material and methods

2.1. Subject characteristics

This work presents a further study in patients with Grade II medial compartment knee osteoarthritis (OA) with a varus deformity, whom we earlier evaluated pre-surgery [18] and 6 months after OWHTO [17].

The study was carried out in accordance with the ethical principles of the Declaration of Helsinki, with obtaining the subject's written informed consent, and was approved by the Independent Interdisciplinary Committee for Ethics Review of Clinical Trials (No. 6 of 07.04.2017).

The study was conducted at the FNCC FMBA (Moscow) and at Buyanov Clinical Hospital. The study included 25 patients assessed before surgery. However, post-surgery data was obtained for 20 patients only (nine males and 11 females; 21 operated knee joints) with medial OA of the knee and a varus deformity due to extra-articular tibial deformity of more than 4 degrees. A total of 21 OWHTO surgeries were performed on the patients. The patient demographics and the mean body mass index (BMI) are presented in Table 1.

Inclusion criteria: medial compartment OA II-III st. according to Kellgren&Lawrence without bone defects; medial compartment chondromalacia according to Outerbridge from second to fourth; hip-knee-ankle (HKA) angle more than 4° and less than 14° varus; moderate or high physical activity patient; body mass index (BMI) less than 35 kg/m2; patient age from 30 to 70 years; knee flexion more than 90°; extension deficiency less than 10°; chondromalacia in the lateral compartment and patellofemoral articulation less than 0–1st. according to Outerbridge; changes in the lateral meniscus no more than 2st. according to Stoller; without ligamentous instability; ineffectiveness of previous conservative treatment methods; pain intensity according to visual analog scale (VAS) $\geq$ 40 mm.

Varus deformity of the lower limb was 6.9° ± 2.1° (range: 4–12°). The target level of correction was 2–3° of valgus.

Functional, clinical, X-ray, and biomechanical assessments were made at three timepoints: just before surgery, 6 and 18 months after surgery.

2.2. Surgical technique

The surgery was performed under spinal anesthesia. The first stage included arthroscopic lavage and debridement of the KJ. Used the technique described in [19] from an oblique 5–6 cm incision in projection of tibial medial condyle. The bone was

Table 1
Patient demographics.

Parameter	Pre-op	6 months	18 months
Number	25	20	20
Age (yrs)	54.7 (39–66)	55.8 (46–65)	54.3 (39–65)
Height (cm)	168 (153–183)	162.1 (153–165)	166.9 (153–183)
Weight (kg)	86.9 (62–123)	88.4 (68–104)	87.1 (62–123)
BMI (kg/m^2)	31.34 (19.8–44.4)	32.8 (25.2–34.4)	30.8 (22.6–37.9)

cut till lateral cortical, without cutting the cortex. The osteotomy wedge was opened to a certain size at the preoperative period corresponding to the size of the tricalcium phosphate block. After that an electron-optical converter control was performed. Fixation of the osteotomy zone was done by using locking plate (Otis + SBM, France).

If a distal femoral osteotomy had to be performed, it was done as the first stage in order to avoid errors when correcting the limb mechanical axis according to the procedure described in [19] with the use of a locking plate system (DePuy Synthes Tomofix, USA). Four patients in the study had a marked deformity that required a two-level osteotomy.

Pooling somewhat different patient groups in the study, we were driven by the fact that, although being different, the surgical operations were, in the first place, aimed to restore the limb axis and reduce the load on the medial compartment of the joint, as well as to improve the joint alignment, an important factor influencing the stereotyped gait pattern. A similar approach has been described in the literature [20].

2.3. Clinical assessment

FLWB X-rays were obtained from all the patients. The varus angle of the affected limb [Huang, J.; 2020] was measured using X-ray images and ranged 4° to 10.3° (mean = 6.52°).

The major mechanical angles were calculated: mLDFA (mechanical lateral distal femoral angle), MPTA (medial proximal tibial angle) and HKA [21].

Knee assessments were done using the scoring systems KSS (Knee Society Score) and KOOS (Knee injury and Osteoarthritis Outcome Score) [22,23]. We used two parts of the KSS, clinical (KSS 1) and functional (KSS 2). The pain syndrome was assessed using a Visual Analogue Scale (VAS) [24].

2.4. Gait analysis

Biomechanical gait parameters were captured using an inertial sensor system (Nevrocor Ltd., Moscow). Five sensors were applied: at the sacrum, the middle third of the thigh and the outer ankles of both legs. The assessment was performed while walking on a flat surface (floor) at an arbitrary pace. The test lasted 30–60 s to capture the necessary number (20–30) of gait cycles to calculate mean parameters with a relatively small standard deviation. Defective strides, stops and turns were excluded from the analysis. Temporal and kinematic parameters were recorded. The temporal parameters included the gait cycle duration (GC, in seconds) and the reciprocity parameter, the beginning of the other leg's GC – second double stance (SDS) at % of GC. The kinematic parameters were the amplitudes and phases of hip and knee movements and were measured in the primary movement direction, i.e., in the sagittal plane (flexion–extension).

For the hip joint, we recorded maximum flexion amplitude at the start of stance phase (a1, degrees) and its phase (x1, % of GC), maximum extension amplitude at the end of stance phase (a2, degrees) and its phase (x2, % of GC) (Figure 1).

For the knee joint, we measured the amplitudes and phases of the first flexion (a1 and x1, respectively), extension (a2 and x2, respectively), and those of the second flexion (in the swing period) (a3 and x3, respectively) (Figure 1).

2.5. Statistical analysis

The obtained data were analyzed using ANOVA in the Statistica 12 software. The medians and quartiles (the 25th and 75th percentiles) were calculated. The data distribution differed from normal, therefore the significance of differences was assessed using the nonparametric Wilcoxon test at $p < 0.05$. Comparisons were made between different timepoints: before surgery versus 6 months after surgery, 6 vs 18 months after surgical treatment. Asymmetry was assessed by comparing the same parameters between the two limbs.

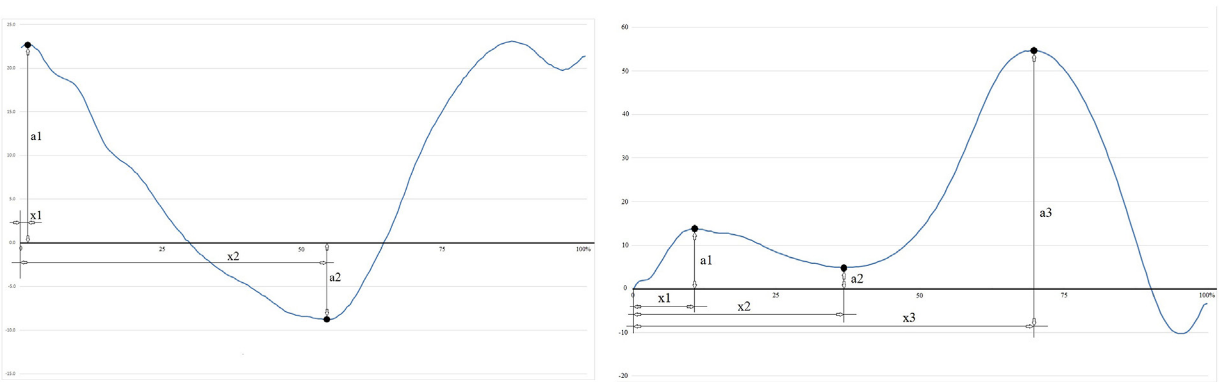

Figure 1. Amplitudes (a) and phases (x) in the hip (left graph) and knee (right graph) goniograms.

3. Results

No loss of correction was found in the follow-up period (see Table 2).

Comparative analyses of clinical and X-ray data obtained at the two timepoints, i.e., 6 and 18 months after surgery, show significant differences in all parameters ($p < 0.05$). All parameters have moderately improved, with the greatest improvements being in VAS pain and knee extension deficit. The absence of MPTA and mLDFA changes shows preservation of the segment correction achieved by the surgery. The range of motion in the operated knee has increased significantly ($p < 0.05$) over this follow-up period, the same being true for flexion and extension.

The over-time changes in the clinical outcomes are presented in Figure 2.

Changes of each parameters in the analyzed time periods were statistically significant ($p < 0.05$). Thus, all four parameters improved with time after surgery.

The results of biomechanical assessments are presented in Tables No. 3–5.

The GC duration at 6 months after surgery did not differ significantly from the pre-op value, but it became significantly shorter at 18 months. SDS did not change (Table 3). There were no significant asymmetries (differences in same parameters between the two limbs).

Table 2
Clinical and X-ray findings at 6 and 18 months after OWHTO.

Parameter	Pre-op	6 months	18 months
MPTA, °	84.5 (80–87.4)	91.3° (88.6°–95.1°) $p < 0.001$ #	91.3° (88.5°–95.4°) $p = 0.82$ *
mLDFA, °	89.1 (85.9–96)	88.5° (85.9°–91.0°) $p < 0.001$ #	88.5° (85.9°–91.0°) $p = 0.149$ *
Flexion amplitude, °	116.6° (90°-130°)	111.4° (80°–125°) $p < 0.001$ #	121.8° (100°–130°) $p < 0.001$ *
Extension deficit, °	2.7° (0°-10°)	0.95° (0°–5°) $p = 0.005$ #	0.4° (0°–2.5°) 0.04*

Difference between pre-op and 6 months' values.
* Difference between 6 and 18 months' values.

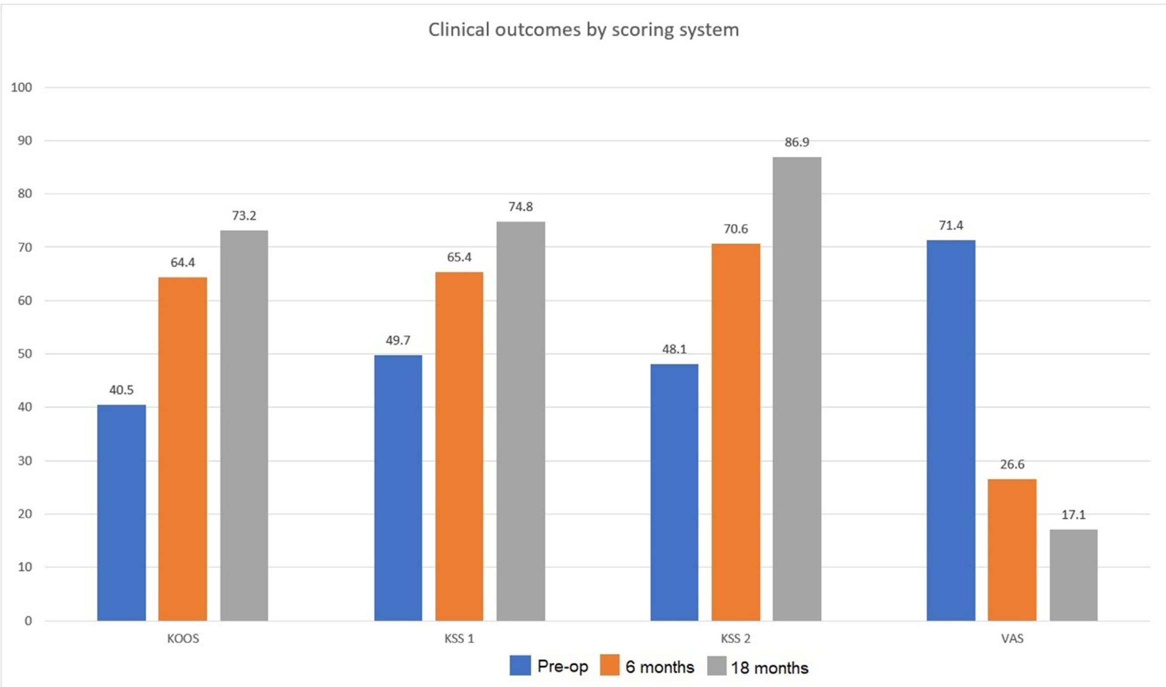

Figure 2. Clinical outcomes at pre-op, 6 and 18 months after OWHTO.

Table 3
Gait cycle duration and the beginning of the other leg GC, SDS.

Parameter	Pre-op		6 months		18 months	
	Intact	Affected	Intact	Affected	Intact	Affected
GC	1.2 [1.1; 1.3] p = 0.846[&]	1.2[1.1; 1.3]	1.2[1.2;1.3] p = 1[#] p = 1[&]	1.2[1.2;1.3] p = 0.758[#]	1.1[1.1;1.2] p = 0.002[*] p = 1[&]	1.1[1.1;1.2] p = 0.002[*]
SDS	49.8 [49.2;50.3] p = 0.72[&]	49.7 [49.3;50.2]	49.9 [49.4;50.1] p = 0.956[#] p = 0.9[&]	49.9 [49.6;50.3] p = 0.522[#]	49.7 [49.4;50.4] p = 0.779[*] p = 0.516[&]	49.9 [49.6;50.3] p = 0.638[*]

[#] Difference between pre-op and 6 months' values.
[*] Difference between 6 and 18 months' values.
[&] Difference between intact and affected limb.

Table 4
Hip amplitudes and phases.

Parameter	Pre-op		6 months		18 months	
	Intact	Affected	Intact	Affected	Intact	Affected
x1	3.8 [2.3;5.7] p = 0.461[&]	3.8 [2;4.6]	4.9 [2.4;6.6] p = 0.659[#] p = 0.597[&]	4.1 [3.3;4.9] p = 0.066[#]	4.6 [3.2;6.3] p = 0.741[*] p = 0.338[&]	4.2 [3;4.8] p = 0.531[*]
a1	19 [16.3;24.1] p = 0.322[&]	18.3 [16.3;20]	20 [17.2;26.4] p = 0.825[#] p = 0.274[&]	17.5 [16.2;22.7] p = 0.034[#]	23.6 [17.5;26.5] p = 0.095[*] p = 0.237[&]	21.8 [18.9;24.4] p = 0.063[*]
x2	58.3 [56.9;60.8] p = 0.801[&]	59.3 [56.9;60.1]	58.2 [56.2;61.6] p = 0.834[#] p = 0.346[&]	59 [57.6;61.1] p = 0.170[#]	57.5 [55.3;60.1] p = 0.1[*] p = 0.125[&]	58.3 [57.3;60.1] p = 0.01[*]
a2	−9.8 [-12.5; −8.8] p = 0.024[&]	−13 [-14.9; −10]	−11.4 [-13.4; −8.1] p = 0.326[#] p = 0.505[&]	−11 [-13.2; −7.4] p = 0.061[#]	−8.6 [-13.6; −6.9] p = 0.085[*] p = 0.345[&]	−11.8 [-13.3; −6.8] p = 0.972[*]

[#] Difference between pre-op and 6 months' values.
[*] Difference between 6 and 18 months' values.
[&] Difference between intact and affected limb.

Six months after surgery, there was a significant increase in the flexion amplitude of the affected limb at the beginning of the stance phase (a1) (p = 0.034) (Table 4). The hip extension amplitude (a2) showed no significant changes.

The hip amplitudes and phases almost did not change at 18 months versus 6 months, except for improved symmetry of the full extension phase on the affected side (x2).

Before surgery, a significant asymmetry was noted in one parameter only, a2 (extension).

Knee motions, amplitudes and phases are presented in Table 5.

According to the obtained data, the knee joint function at 6 months after surgery did not differ significantly from that before surgery. Moreover, comparison between values obtained at 6 and 18 months showed no significant changes as well.

Table 5 demonstrates an interesting peculiarity of the knee joint function. Before surgery, the function of both KJ was symmetric. We did not get a single statistically significant difference between the same parameters. Six months after surgery, the first flexion amplitude (a1) at the beginning of GC, i.e., when the body weight is being transferred from one limb to the other, was smaller than before surgery. Thus, this amplitude became asymmetric. Eighteen months after the operation, the differences are statistically unreliable. Thus, the symmetry has been restored. The mean a1 returned to the pre-op level.

4. Discussion

The achieved surgical correction remained stable 6 and 18 months after surgery.

The assessments of the OWHTO clinical outcomes with the KOOS, KSS 1, KSS 2, and VAS scores showed a significant improvement in the function of the operated knee over the periods from pre-op to month 6 and from month 6 to month 18 after surgery. All the scores showed improvement, with the largest one being in the KSS 2 assessment of the knee function. The KSS 1 and KOOS scores also showed positive dynamics, although not as great as 6 months after the corrective surgery. These data suggest that maximum improvement in knee function and VAS pain reduction occurred during the first

Table 5
Knee amplitudes and phases.

Parameter	Pre-op		6 months		18 months	
	Intact	**Affected**	**Intact**	**Affected**	**Intact**	**Affected**
x1	16 [14.5;18.2] *p* = 1[&]	16 [14.8;18.3]	16.8 [15.1;18.8] *p* = 1[#] *p* = 0.92[&]	16.8 [15.5;18.9] *p* = 0.402[#]	16.8 [14.3;19.1] *p* = 0.709[*] *p* = 0.597[&]	16.6 [13.8;17.9] *p* = 0.151[*]
a1	17.4 [13.7;21.2] *p* = 0.056[&]	14.4 [9;19.13]	16.9 [15;26.3] *p* = 0.48[#] *p* = 0.014[&]	13.1 [10.4;19.2] *p* = 0.099[#]	17.4 [12.2;21.2] *p* = 0.099[*] *p* = 0.195[&]	14.7 [10.4;18.1] *p* = 0.867[*]
x2	43.9 [42.4;45.6] *p* = 0.318[&]	41.7 [37.3;46.2]	42.9 [38.1;46.8] *p* = 0.851[#] *p* = 0.116[&]	39.9 [33.9;43.8] *p* = 0.295[#]	41.6 [38.8;44.7] *p* = 0.526[*] *p* = 0.083[&]	36.6 [32.6;43.1] *p* = 0.867[*]
a2	9 [5.8;11.3] *p* = 0.93[&]	8.9 [4;12.1]	9.8 [8.7;11.9] *p* = 0.152[#] *p* = 0.458[&]	9.6 [6.2;12.1] *p* = 0.421[#]	9.8 [8;11] *p* = 0.889[*] *p* = 0.421[&]	10.4 [8.7;11.6] *p* = 0.313[*]
x3	75.8[74.9;77.2] *p* = 0.461[&]	75.6 [74.5;76.3]	75.5 [74.6;77] *p* = 0.93[#] *p* = 0.385[&]	75.3 [74.7;76] *p* = 0.574[#]	75.4 [73.1;76] *p* = 0.016[*] *p* = 0.831[&]	74.8 [73;76.4] *p* = 0.113[*]
a3	62 [57.7;68.1] *p* = 0.985[&]	64 [55.2;69]	66.1 [58.3;71.4] *p* = 0.332[#] *p* = 0.91[&]	66.9 [57.1;70.2] *p* = 0.427[#]	64 [53.9;69.3] *p* = 0.52[*] *p* = 0.538[&]	62.6 [60;66.1] *p* = 0.566[*]

[#] Difference between pre-op and 6 months' values.
[*] Difference between 6 and 18 months' values.
[&] Difference between intact and affected limb.

6 months after OWHTO; however, the knee function continued to restore, although more slowly, during the period of 6–18 months after surgery. Similar score-based results are described by Odum and Habib [23,25].

Studies by Keyt; Thompson; and Sawaguchi; assessed the results of valgus producing correction osteotomies 24 months after surgery [26–28]. Although the follow-up period in those studies was longer than in ours, the results are consistent in terms of clinical outcome assessments by the scoring systems and the VAS pain syndrome assessment. Lawrence et al. obtained similar results at 12 months after surgery; they also found a significant slight decrease in the range of motion 10 years after surgery [29].

Thus, the long-term clinical outcomes of our study are consistent with those of other authors [25,30,26–29]. First of all, they include a reduction in VAS pain and improvements in the knee function as assessed by KOOS and KSS at 6 and 18 months after OWHTO.

The main finding of the biomechanical part of the study is that the KJ function almost did not change either 6 or 18 months after surgery.

A slight reduction of the GC duration at 18 months post-surgery, along with unchanged hip and knee amplitudes, suggests that the walking speed could have increased. The study by Morin [10] found that the key spatiotemporal gait parameters remained unchanged at one year after correction surgery, but there were no data on the joint kinematics. Another study by van Egmond [31] also confirmed the absence of changes in the spatiotemporal parameters one year after surgery versus before surgery. Six months after surgery, however, the operated knee kinematics showed a decrease in the first flexion (denoted here by a1) and extension amplitudes (a2), while the swing flexion amplitude (a3) remained the same. In their paper [31], van Egmond noted some deterioration in the function of the operated joint 12 months after surgery compared with pre-surgery. There were also some minor improvements over the following 12 months. These findings are consistent with the study by Lind [11], which reports similar changes in the operated knee kinematics at 12 months after surgery.

In our study, we have found that the period of 6 months after surgery is not enough for the knee joint to recover. Its function remains slightly asymmetric due to the decreased amplitude a1. During the following year, however, a1 increases to preoperative values.

While the clinical data demonstrates apparent improvement in several clinical parameters, the biomechanical data shows only minor, though also positive, functional changes.

Thus, we can see some difference in the assessment of recovery dynamics based on clinical versus biomechanical parameters. While the clinical scores demonstrated significant improvement, gait analysis and knee kinematics showed almost no changes over the follow-up period. As the reported improvement was mainly based on subjective assessment scores (VAS, KOOS and KSS2), completed by the patients themselves, it can be mostly attributed to a significant psychological improvement and increased load tolerance of the operated limb rather than to some clinical (objective) improvement. When assessed by KSS1, the improvement was mostly related to an increase in the flexion amplitude in the supine position.

The study hypothesis has not been confirmed. The functional biomechanical parameters remained virtually unchanged after OWHTO.

This study has certain limitations. Individual clinical features of patients may have a strong effect on biomechanical parameters sensitive to peculiarities in the knee function. Therefore, the inter-individual variability of the functional result of surgical treatment has been quite high. Almost all patients enrolled in our study were overweight and hence with additional load on their KJs.

Although there were no postoperative complications, the individual rehabilitation treatment varied both quantitatively and qualitatively among the patients. It was technically not possible for us to provide all patients with rehabilitation according to a single standard. Another limitation of the study was the lack of assessment of the function and OA grade of the contralateral KJ.

This study suggests that biomechanical gait analysis should play a more important part in routine clinical assessments of patients, both before surgery and, the more so, in the first months of rehabilitation.

5. Conclusion

According to the study data, there was a moderate clinical improvement, as assessed by VAS, KOOS and KSS, in the long-term follow-up period. The biomechanical changes were minor and manifested in decreased GC duration, which indirectly indicates an increase in walking speed.

Thus, we have found an inconsistency between the dynamics of clinical and biomechanical parameters. While the clinical parameters continued to improve beyond 6 months after surgery, the functional biomechanical parameters remained virtually unchanged throughout the entire follow-up period.

The observed changes in gait biomechanics suggest that intensive rehabilitation with monitoring of biomechanical parameters is most needed during the first 6 months after surgery.

Author contributions

DS – contributed to conception and design of the study, investigating of patients, analyzing data, wrote the draft of the manuscript, final article writing.

AP selection of patients for the study, clinical examination, data analysis, draft editing.

SK – patient research, data analysis, organization of admission of patients for examination, editing draft.

AA – patient research, data analysis, statistical analysis, draft article writing, final article writing.

FL – selection of patients for the study, clinical examination, analysis of clinical data, writing the clinical draft.

AN – selection of patients for the study, clinical examination, analysis of clinical data.

NZ – general supervising.

All authors contributed to manuscript revision, read, and approved the submitted version.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Fujisawa Xie K, Han X, Jiang X, et al. The effect of varus knee deformities on the ankle alignment in patients with knee osteoarthritis. J Orthop Surg Res 2019;14:134. doi: https://doi.org/10.1186/s13018-019-1191-0.

[2] Briem K, Ramsey DK, Newcomb W, Rudolph KS, Snyder-Mackler L. Effects of the amount of valgus correction for medial compartment knee osteoarthritis on clinical outcome, knee kinetics and muscle co-contraction after opening wedge high tibial osteotomy. J Orthop Res 2007;25(3):311–8. doi: https://doi.org/10.1002/jor.20326.

[3] Whatling GM, Biggs PR, Elson DW, Metcalfe A, Wilson C, Holt C. High tibial osteotomy results in improved frontal plane knee moments, gait patterns and patient-reported outcomes. Knee Surgery, Sports Traumatol, Arthrosc: Official J ESSKA 2020;28(9):2872–82. doi: https://doi.org/10.1007/s00167-019-05644-7.

[4] Gao L, Madry H, Chugaev DV, Denti M, Frolov A, Burtsev M, et al. Advances in modern osteotomies around the knee: Report on the Association of Sports Traumatology, Arthroscopy, Orthopaedic surgery, Rehabilitation (ASTAOR) Moscow International Osteotomy Congress 2017. J Exp Orthop 2019;6(1):9. doi: https://doi.org/10.1186/s40634-019-0177-5.

[5] Murray R, Winkler PW, Shaikh HS, Musahl V. High Tibial Osteotomy for Varus Deformity of the Knee. J Am Acad Orthopaed Surg Global Res Rev 2021;5(7):e21.00141. doi: https://doi.org/10.5435/JAAOSGlobal-D-21-00141.

[6] Peng H, Ou A, Huang X, Wang C, Wang L, Yu T, et al. Osteotomy Around the Knee: The Surgical Treatment of Osteoarthritis. Orthop Surg 2021;13(5):1465–73. doi: https://doi.org/10.1111/os.13021.

[7] Sarwar S, Lu J, Marcella C, Ming-liang J. Indications and clinical outcomes of High Tibial Osteotomy: a literature review. J Orthoped Muscular Syst 2019;2(1):1007.
[8] Sabzevari S, Ebrahimpour A, Roudi MK, Kachooei AR. High tibial osteotomy: a systematic review and current concept. Arch Bone Joint Surg 2016;4 (3):204–12.
[9] Black MS, d'Entremont AG, McCormack RG, Hansen G, Carr D, Wilson DR. The effect of wedge and tibial slope angles on knee contact pressure and kinematics following medial opening-wedge high tibial osteotomy. Clin Biomech (Bristol, Avon) 2018;51:17–25. doi: https://doi.org/10.1016/j.clinbiomech.2017.10.021.
[10] Morin V, Pailhe R, Duval BR, et al. Gait analysis following medial opening-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2017;26 (6):1838–44. doi: https://doi.org/10.1007/s00167-017-4421-1.
[11] Lind M, McClelland J, Wittwer JE, Whitehead TS, Feller JA, Webster KE. Gait analysis of walking before and after medial opening wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2013;21:74–81. doi: https://doi.org/10.1007/s00167-011-1496-y.
[12] Leitch KM, Birmingham TB, Dunning CE, GiffinJ R. Medial opening wedge high tibial osteotomy alters knee moments in multiple planes during walking and stair ascent. Gait Posture 2015;42(2):165–71. doi: https://doi.org/10.1016/j.gaitpost.2015.05.005.
[13] Liu X, Chen Z, Gao Y, Zhang J, Jin Z. High Tibial Osteotomy: Review of Techniques and Biomechanics. J Healthcare Eng 2019;2019:8363128. doi: https://doi.org/10.1155/2019/8363128.
[14] Bode G, von Heyden J, Pestka J, Schmal H, Salzmann G, Südkamp N, et al. (2015) Prospective 5-year survival rate data following open-wedge valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2015;23(7):1949–55. doi: https://doi.org/10.1007/s00167-013-2762-y.
[15] Da Silva HGPV, Zorzi AR, da Silva HPV, de Miranda JB. Gait analysis in short-term follow-up of medial opening wedge high tibial osteotomy. Eur J Orthop Surg Traumatol 2018;28(5):939–46. doi: https://doi.org/10.1007/s00590-017-2099-1.
[16] Da Cunha RJ, Kraszewski AP, Hillstrom HJ, Fragomen AT, Rozbruch SR. Biomechanical and Functional Improvements Gained by Proximal Tibia Osteotomy Correction of Genu Varum in Patients with Knee Pain. HSS J: Musculoskelet J Hospital Special Surg 2020;16(1):30–8. doi: https://doi.org/10.1007/s11420-019-09670-6.
[17] Skvortsov D, Kaurkin S, Prizov A, Altukhova A, Goncharov E, Nikitin A. Gait analysis and knee joint kinematics before a and 6 month after of corrective valgus osteotomy at patients with medial knee arthritis. Int Orthop 2022. doi: https://doi.org/10.1007/s00264-022-05370-9.
[18] Skvortsov D, Kaurkin S, Prizov A, Altukhova A, Troitskiy A, Lazko F. Biomechanical Changes in Gait Patterns of Patients with Grade II Medial Gonarthritis. Diagnostics 2021;11:1242. doi: https://doi.org/10.3390/diagnostics11071242.
[19] Saragaglia D, Nemer C, Colle PE. (2008) Computer-assisted double level osteotomy for severe genu varum. Sports Med Arthrosc Rev 2008;16(2):91–6. doi: https://doi.org/10.1097/JSA.0b013e318172b562.
[20] Fürmetz J, Patzler S, Wolf F, et al. Tibial and femoral osteotomies in varus deformities - radiological and clinical outcome. BMC Musculoskelet Disord 2020;21:201. doi: https://doi.org/10.1186/s12891-020-03232-2.
[21] Huang J, Tian F, Zhang Z, Shi W, Lin J, Chen L, Yang H. Reliability and concurrent validity of angle measurements in lower limb: EOS 3D goniometer versus 2D manual goniometer. J. Orthop Transl 2020;24(2020):96–102. doi: https://doi.org/10.1016/j.jot.2020.05.002.
[22] Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). Arthritis Care Res (Hoboken) 2011;63(Suppl 11(0 11)):S208–28. doi: https://doi.org/10.1002/acr.20632.
[23] Odum SM, Fehring TK, Knee Society Crosswalk Writing Group. Can Original Knee Society Scores Be Used to Estimate New 2011 Knee Society Scores?. Clin Orthop Relat Res 2017;475(1):160–7. doi: https://doi.org/10.1007/s11999-016-4886-0.
[24] Huskisson EC. Measurement of pain. Lancet 1974;304:1127–31.
[25] Habib MK, Khan ZA. Radiological, functional, and anatomical outcome in patients with osteoarthritic knee undergoing high tibial osteotomy. SICOT J 2019;5:12. doi: https://doi.org/10.1051/sicotj/2019009.
[26] Keyt LK, Hevesi M, Levy BA, Krych AJ, Camp CL, Stuart MJ. High Tibial Osteotomy with a Modern Polyetheretherketone (PEEK) System: Mid-Term Results at a Mean of 6 Years Follow-Up. J Knee Surg 2020. doi: https://doi.org/10.1055/s-0040-1721090.
[27] Thompson KA, Darden CN, Katsman A, Alaia MJ, Strauss EJ, Jazrawi LM. Short-Term Clinical Outcomes of High Tibial Osteotomy with the iBalance HTO System. Bull Hosp Jt Dis (2013) 2019;77(4):256–62.
[28] Sawaguchi T, Takeuchi R, Nakamura R, et al. Outcome after treatment of osteoarthritis with open-wedge high-tibial osteotomy with a plate: 2-year results of a Japanese cohort study. J Orthop Surg 2020. doi: https://doi.org/10.1177/230949901988799.
[29] Lau LCM, Fan JCH, Chung K-Y, Cheung K-W, Man GCW, Hung Y-W, et al. Satisfactory long-term survival, functional and radiological outcomes of open-wedge high tibial osteotomy for managing knee osteoarthritis: Minimum 10-year follow-up study. J Orthopaed Transl 2021;26:60–6. doi: https://doi.org/10.1016/j.jot.2020.03.003.
[30] Birmingham TB, Giffin JR, Chesworth BM, Bryant DM, Litchfield RB, Willits K, et al. Medial opening wedge high tibial osteotomy: A prospective cohort study of gait, radiographic, and patient-reported outcomes. Arthritis Rheum 2009;61:648–57. doi: https://doi.org/10.1002/art.24466.
[31] van Egmond N, Stolwijk N, van Heerwaarden R, van Kampen A. Keijsers Gait analysis before and after corrective osteotomy in patients with knee osteoarthritis and a valgus deformity. NLW Knee Surg Sports Traumatol Arthrosc 2017;25(9):2904–13. doi: https://doi.org/10.1007/s00167-016-4045-x.