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Postural Stability and Regulation before and after High Tibial Osteotomy and Rehabilitation

Kay Brehme [1], Thomas Bartels [1], Martin Pyschik [1], Manuel Jenz [2], Karl-Stefan Delank [2], Kevin G. Laudner [3] and René Schwesig [2,*]

[1] Sports Clinic Halle, Center of Joint Surgery, 06108 Halle (Saale), Germany; kay.brehme@sportklinik-halle.de (K.B.); thomas.bartels@sportklinik-halle.de (T.B.); martin.pyschik@sportklinik-halle.de (M.P.)

[2] Department of Orthopaedic and Trauma Surgery, Martin-Luther-University Halle-Wittenberg, Ernst-Grube-Str. 40, 06120 Halle (Saale), Germany; manuel.jenz@freenet.de (M.J.); stefan.delank@uk-halle.de (K.-S.D.)

[3] Department of Health Sciences, University of Colorado, Colorado Springs, CO 80918, USA; klaudner@uccs.edu

* Correspondence: rene.schwesig@uk-halle.de; Tel.: +49-345-557-1317; Fax: +49-345-557-4899

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Featured Application: Knee osteoarthrosis (OA) is a common orthopedic problem often surgically treated using a high tibial osteotomy (HTO). Unfortunately, little is known regarding the effects of HTO on postural stability and regulation. The purpose of our study was to provide a better understanding of the underlying mechanisms of postural regulation, especially the potential change in postural subsystems following HTO.

Abstract: Knee osteoarthrosis (OA) is a widespread orthopedic problem and a high tibial osteotomy (HTO) is a common treatment to minimize degeneration of the affected compartment. The primary aim of this study was to evaluate the postural regulation and stability among patients who underwent HTO and rehabilitation. This prospective study included 32 patients (55.3 ± 5.57 years) diagnosed with medial tibiofemoral OA. Each subject completed postural regulation and stability testing (Interactive Balance System), as well as pain intensity (visual analogue scale) and quality of life questionnaires (SF-36) prior to HTO (exam 1), and at six weeks (exam 2), twelve weeks (exam 3) and six months (exam 4) post HTO. For postural comparison, all patients were matched (sex, age, height) with asymptomatic subjects. Significant time effects (exam 1 vs. exam 4) were found for weight distribution index (WDI; $\eta_p^2 = 0.152$), mediolateral weight distribution $\eta_p^2 = 0.163$) and anterior–posterior weight distribution $\eta_p^2 = 0.131$). The largest difference (exam 3: $\eta_p^2 = 0.251$) and the most significant differences to the matched sample were calculated for the stability indicator (exam 1: $\eta_p^2 = 0.237$; exam 2: $\eta_p^2 = 0.215$; exam 3: $\eta_p^2 = 0.251$; exam 4: $\eta_p^2 = 0.229$). Pain intensity showed a significant reduction ($\eta_p^2 = 0.438$) from exam 1 (50.7 ± 20.0 mm) to exam 4 (19.3 ± 16.0 mm). Physical pain was the quality of life parameter with the largest improvement between exams 1 and 4 ($\eta_p^2 = 0.560$). HTO allows patients to improve their mediolateral weight distribution, whereas postural stability is consistently lower than in asymptomatic subjects. This surgery leads to marked improvements in quality of life and pain.

Keywords: knee osteoarthrosis; surgery; posturography; postural subsystems; pain; quality of life

1. Introduction

For more than 25% of patients under the age of 70 years, knee osteoarthritis (OA) is a widespread orthopedic problem [1]. Kurtz et al. [2] reported a predicted increase in prevalence to 40% between 2005 and 2030 for Western Europe and North America.

High tibial osteotomy (HTO) is a well-established and often recommended surgical option for medial compartment knee OA in patients with varus malalignment [3,4]. This surgical intervention is indicated for varus deformities of 5° or greater in patients with cartilage defects and who are able to defer total knee arthroplasty (TKA) [5,6]. HTO has been shown to reduce pain, improve function and slow the progression of OA [7]. Previous research has investigated the effectiveness of using an opening-wedge HTO to evaluate cartilage quality [8–11] and compared HTO and knee joint distraction as an alternative surgical treatment for OA [6,12]. Bode et al. [5] compared the survival rates (defined as the absence for need of reintervention) of patients with less than 5° varus deformity when treated with autologous chondrocyte implantation and additional HTO compared to those treated with ACI alone. Bastard et al. [13] investigated the influence of HTO on return to sport at one year postoperative using the Tegner score (primary outcome) and quality of life questionnaire (SF-36).

Unfortunately, the effects of HTO on postural stability and regulation have received little attention. Hunt et al. [14] found that standing balance in patients with OA is not significantly different following HTO, but this was only assessed 12 months postoperative. Zhang et al. [15] evaluated the circadian rhythm of balance control in patients with OA using posturography and found reduced postural performance and pain in the morning compared to the early afternoon.

The current study is based on the longitudinal study design of Bartels et al. [16] with a postoperative follow-up of six months. Four hypotheses were proved:

(1) Medial tibiofemoral OA and HTO will induce unbalanced mediolateral weight distribution;
(2) Postural stability will be reduced before and after HTO;
(3) After medial tibiofemoral OA/HTO and compared to healthy matched individuals the cerebellar and somatosensory subsystem will display the largest changes;
(4) Pain perception and quality of life will significantly improve following HTO and rehabilitation.

2. Materials and Methods

2.1. Subjects

Thirty-two (84%) of an initial 38 included male patients completed all four examinations (exams). For the statistical analysis, only data from these 32 participants were included (Table 1).

Table 1. Demographic and anthropometric characteristics of patients (exam 1, n = 32).

Sex, Male:Female	32:0
Age (year)	55.3 ± 5.57 (42.0–62.0)
Height (m)	1.80 ± 0.07 (1.70–2.01)
Weight (kg)	99.4 ± 13.4 (77.8–129.1)
Body mass index (kg/m^2)	30.7 ± 3.65 (24.0–39.6)
Duration of pain (month)	28.3 ± 20.2 (4–96)
Affected side	n = 12 left; n = 20 right
Dominant and non-dominant leg	n = 13 left; n = 18 right (1 subject did not indicate dominance)

Results reported as mean ± standard deviation (range).

No relation (Chi-Quadrat: 2.306, $p = 0.129$) was calculated between the side of diagnosis and the side of the dominant or non-dominant leg. All included patients had moderate OA (Kellgren–Lawrence grade: 3). Prior to data collection, all participants provided written consent to participate after being informed of all study procedures and risks. The study was approved by the ethical committee of Martin-Luther-University Halle-Wittenberg (approval number: 2018-66).

2.2. Measurement Set-Up

Figure 1 shows the prospective and longitudinal design used for this study. All patients had been diagnosed with medial knee compartmental OA verified by MRI, arthroscopy of the knee and clinical check performed by an experienced (30–40 HTO surgeries yearly) orthopedist. Only one surgeon was included in this examination to ensure the highest level of observation equality.

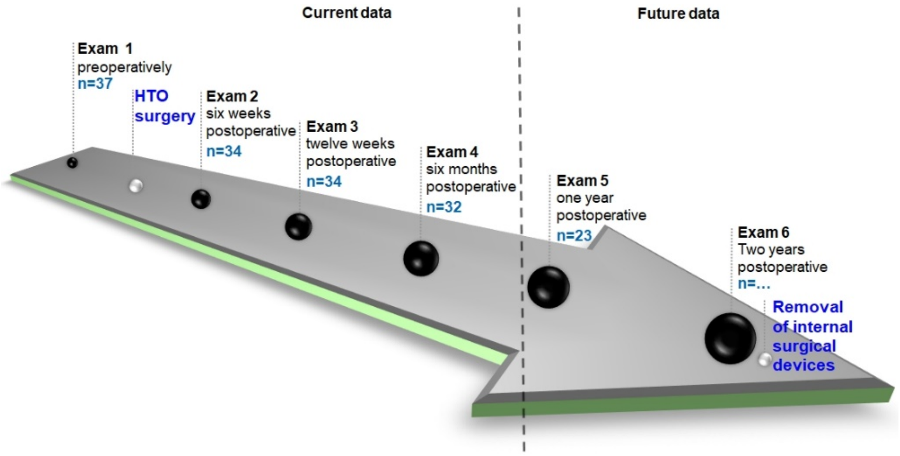

Figure 1. Flow chart of the longitudinal study design.

In total, 37 patients with symptomatic medial knee compartmental OA were initially (exam 1) recruited between May 2018 and August 2019 in this single-center (SportsClinic Halle) controlled trial. The following inclusion criteria were used:

- A body mass index (BMI) of less than 40 kg/m^2 based on an age range from 18 to 70 years;
- A tibiofemoral angle of less than 10° of varus;
- Intact knee ligaments;
- An asymptomatic range of motion (minimum of 120° flexion);
- Chronic knee pain during rest and motion.

Patients with instability of the knee ligaments and contralateral knee OA requiring treatment were excluded, as were those with primary patellofemoral OA, bi-compartmental OA, tibial or femoral osteonecrosis and those with a history of an inflammatory rheumatic disease. The patients did not participate in the study if they were unable to perform the balance tests (posturography) owing to pain or limited motion of the lower limb [17].

Patients were assessed initially (exam 1) and then again postoperatively at six weeks (exam 2), twelve weeks (exam 3) and six months (exam 4) (authors are currently investigating 2-year follow-up). Between exam 1 and exam 2, the HTO surgery was conducted. The time between exam 1 and HTO surgery was on average 6.38 ± 10.2 days (range: 0–40 days). Overall, 34% (11/32) of patients had surgery and exam 1 on the same day; 22% (7/32) of patients had a time interval of at least seven days. The primary reasons for these deviations were mostly organizational issues and the short-term illnesses of patients. The aim of this study was to determine the long-term impacts of HTO and the subsequent standardized rehabilitation and individual treatment (Figure 1, Table A1). All measurements were performed at the same time of day and in a quiet room to minimize any disruptions during testing.

2.3. Surgery and Medication

The surgical procedure used consisted of a bi-plane medial-based opening-wedge HTO, including a distal release of the superficial medial collateral ligament fibers. The aim was to shift the weight-bearing line laterally, with the post-operative mechanical axis running laterally through the tibial plateau at 62% of its entire width (measured from the medial side) [6]. Only one surgeon (KB) was used for all procedures to avoid any surgeon bias. The LOQTEQ Osteotomy Plate system (aap Implants Inc. Dover, DE, USA) was used for fixation.

Using standing whole leg radiographs, the amount of needed correction was determined using the Miniaci method [18]. The x-raying of the knee joint (bi-plane) was performed at two weeks and four weeks postoperatively in order to judge the process of bone healing. The axis control using standing whole leg radiographs was only conducted preoperatively, because it had no impact on the rehabilitation process.

Concerning medication, Mono-embolex (a low molecular heparin) was given for 20 days postoperative to reduce the risk of thrombosis. Diclofenbeta and Imbun (non-steroidal anti-inflammatory/antirheumatic drugs) were used for perioperative pain management (Diclofenbeta: three times for three days and afterwards once per day until removing sutures; Imbun: if necessary, one-two times per day). The pain management (Imbun) ended after a 20-day postoperative period.

2.4. *Assessments*

2.4.1. Posturography

Postural regulation and stability were measured using the Interactive Balance System (IBS, neurodata, Vienna, Austria). This system provides a comprehensive and sufficient reference database of asymptomatic subjects (n = 1724) stratified by age and gender [19]. The IBS is well established and commonly used in scientific research, and considered as valid [20–23] and reliable [24–26]. For example, the intraobserver reliability calculated by intraclass correlation coefficients moved from 0.71 to 0.95 for all parameter and tests.

For a valid comparison with asymptomatic subjects, we performed a matched-pairs technique [16] using the parameters age ($p = 0.412$), gender ($p = 1.000$) and body height ($p = 0.272$). For this reason, recruitment of an asymptomatic control group was not necessary.

All participants were tested by the same investigator (MJ) on the vertical force platform (IBS). All measurements were conducted at the same time of day and in a quiet room to minimize any disruptions during testing.

The IBS consists of four independent force plates (acquisition frequency: 32 Hz, recording time per trial: 32 s) in order to measure forefoot and heel forces separately. A detailed description regarding parameters (including interpretation and explanation of functional frequency bands), test positions/conditions and instructions for subjects has already been published [16,23,27,28].

2.4.2. Pain Assessment (Visual Analogue Scale)

To evaluate pain intensity of the affected limb, the Visual Analogue Scale (VAS) was used [29]. The VAS consists of a 100-mm line whose endpoints were declared as "no pain" (at 0 mm) and "insupportable pain" (at 100 mm). The patients were asked before the posturography to locate the level of pain on the line with a small vertical mark [15].

2.4.3. Quality of Life Assessment (SF-36)

Health-related quality of life (HRQL) was evaluated using the SF-36 questionnaire (German version) [30,31]. Mc Horney et al. [32] reported an Intraclass correlation coefficient (ICC) of 0.85. Psychometric validation of the German SF-36 revealed comparable results concerning reliability, and construct validity with other European samples [30,31,33]. Based on 36 questions, eight different subscales describing physical and mental health can be assessed. These subscales include Physical Functioning (PF), Role Physical (RP), Bodily Pain (BP), and General Health (GH), which represent the physical aspect, Vitality (VT), Social Functioning (SF), Role Emotional (RE), and Mental Health (MH) represent the mental aspect. Finally, and in order to allow for interpretation and discussion of the results of this study, a transformation of the subscales into a physical health component summary score (PCS) and a mental health component summary score (MCS) was performed [34].

2.4.4. Statistics

An a priori power analysis (nQuery 4.0, Statistical solutions Ltd., Cork, Ireland) was performed to determine the sample size using a two-sided hypothesis test at an alpha level of 0.05. In line with other authors [6,12] the sample size calculation was performed based on noninferiority using a power of 80%. Van der Woude et al. [6] recommended studies account for possible attrition and/or insufficient data quality. Therefore, the sample size was increased by 15%.

For all parameters, mean, standard deviation, 95% confidence intervals were reported. In the run-up to the inference statistical analyses, all variables were tested for normal distribution (Shapiro–Wilk Test). Mean differences between exams (1–4) and groups (HTO patients vs. matched subjects) were tested using a one-factorial (time or group) univariate general linear model. The variance analysis was divided into three parts according to and described in detail in Bartels et al. [16].

The critical level of significance was adjusted using the Bonferroni correction. After this correction, a significance level (p) of 0.05 was divided by the number of posturographic tests (9). Differences between means were considered as statistically significant if p values were <0.006 or partial eta squared (partial-η^2 (η_p^2)) values were greater than 0.10 [35].

All statistical analyses were performed using SPSS version 25.0 for Windows (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Normal Distribution and Variance Homogeneity

Only the variable BMI ($p = 0.063$) had a normal distribution. Regarding variance homogeneity, one parameter (stability indicator: $p = 0.005$) did not show variance homogeneity. Otherwise, all p-values were higher than 0.078 (synchronization) indicating that the variances from all other variables were not significantly different.

No significant differences between patients and asymptomatic references were calculated for age ($p = 0.412$, $\eta_p^2 = 0.011$) and height ($p = 0.272$, $\eta_p^2 = 0.019$). In contrast, significant mean differences were detected for weight ($p = 0.001$, $\eta_p^2 = 0.152$) and BMI ($p = 0.007$, $\eta_p^2 = 0.110$). The body weight for the patients was clearly higher (patients: 99.4 ± 13.4 kg vs. reference group: 88.4 ± 13.1 kg) than for the reference group and was stable over the six-month period ($p = 0.567$, $\eta_p^2 = 0.018$).

3.2. Longitudinal Analysis

Longitudinal analysis within the HTO patients can be viewed in Tables 2 and 3, and in Figures 2–4. For posturographic parameters, we only found a significant main effect for time (preoperative vs. six months post-operation) in weight distribution index (WDI) (Table 2; Figure 3B).

Table 2. Descriptive comparison of five examinations and analysis of variance, calculation of effect size (η_p^2) only for bilateral posturographic parameters (n = 32). Grey marked the descriptive values (mean ± standard deviation in column 1) and four cross-sectional comparisons with the reference matched sample (p/η_p^2).

Parameter / Matched Sample	Examinations (Exam)				Variance Analysis		
	Exam 1 Preoperative	Exam 2 6 Weeks Postoperative	Exam 3 12 Weeks Postoperative	Exam 4 6 Months Postoperative	Comparison of Exam 1 vs. Exam 4		Comparison of Adjacent Exams
					p	η_p^2	η_p^2
Visual and Nigrostriatal	18.4 ± 5.44	20.9 ± 22.1	21.6 ± 22.0	**17.7 ± 5.07**	0.635	0.014	-
16.6 ± 6.44	0.213/0.025	0.289/0.018	0.220/0.024	0.431/0.010	reference matched sample		
Peripheral-vestibular	10.3 ± 3.13	9.78 ± 2.15	**9.65 ± 2.00**	9.93 ± 2.01	0.145	0.059	-
9.67 ± 3.46	0.416/0.011	0.872/0.000	0.983/0.000	0.708/0.002	reference matched sample		
Somatosensory	4.81 ± 1.50	**4.48 ± 1.35**	4.62 ± 1.17	4.62 ± 1.36	0.114	0.062	1 vs. 2 (0.152)
4.18 ± 1.39	0.086/0.047	0.382/0.012	0.175/0.029	0.198/0.027	reference matched sample		
Cerebellar	**0.90 ± 0.27**	0.91 ± 0.30	0.91 ± 0.24	0.93 ± 0.32	0.810	0.008	-
0.75 ± 0.22	0.015/0.092	0.017/0.088	**0.005/0.118**	**0.010/0.103**	reference matched sample		
Stability indicator	27.1 ± 8.59	26.3 ± 8.03	26.5 ± 7.31	26.7 ± 8.20	0.728	0.012	-
19.2 ± 5.40	**<0.001/0.237**	**<0.001/0.215**	**<0.001/0.251**	**<0.001/0.229**	reference matched sample		
Weight distribution index	6.60 ± 1.78	7.13 ± 2.26	6.01 ± 2.05	6.01 ± 2.09	**0.003**	**0.152**	2 vs. 3 (0.297)
6.11 ± 3.80	0.513/0.007	0.198/0.027	0.896/0.000	0.897/0.000	reference matched sample		
Synchronization	622 ± 108	589 ± 142	610 ± 136	**628 ± 143**	0.390	0.031	-
623 ± 157	0.978/0.000	0.368/0.013	0.722/0.002	0.901/0.000	reference matched sample		
Anterior–posterior	**5.30 ± 8.16**	7.54 ± 6.93	5.81 ± 6.91	7.44 ± 6.57	0.031	0.095	1 vs. 2 (0.170) 3 vs. 4 (0.124)
0.58 ± 10.7	0.051/0.060	**0.003/0.134**	0.023/0.080	**0.003/0.134**	reference matched sample		
Mediolateral	−0.35 ± 5.42	−0.19 ± 7.93	−0.26 ± 5.27	−0.58 ± 4.13	0.966	0.002	-
0.31 ± 5.55	0.628/0.004	0.769/0.001	0.675/0.003	0.469/0.008	reference matched sample		

Values are given as mean ± standard deviation. Significance level: $p < 0.006$ or $\eta_p^2 \geq 0.10$. Significant differences and performance maxima marked in bold.

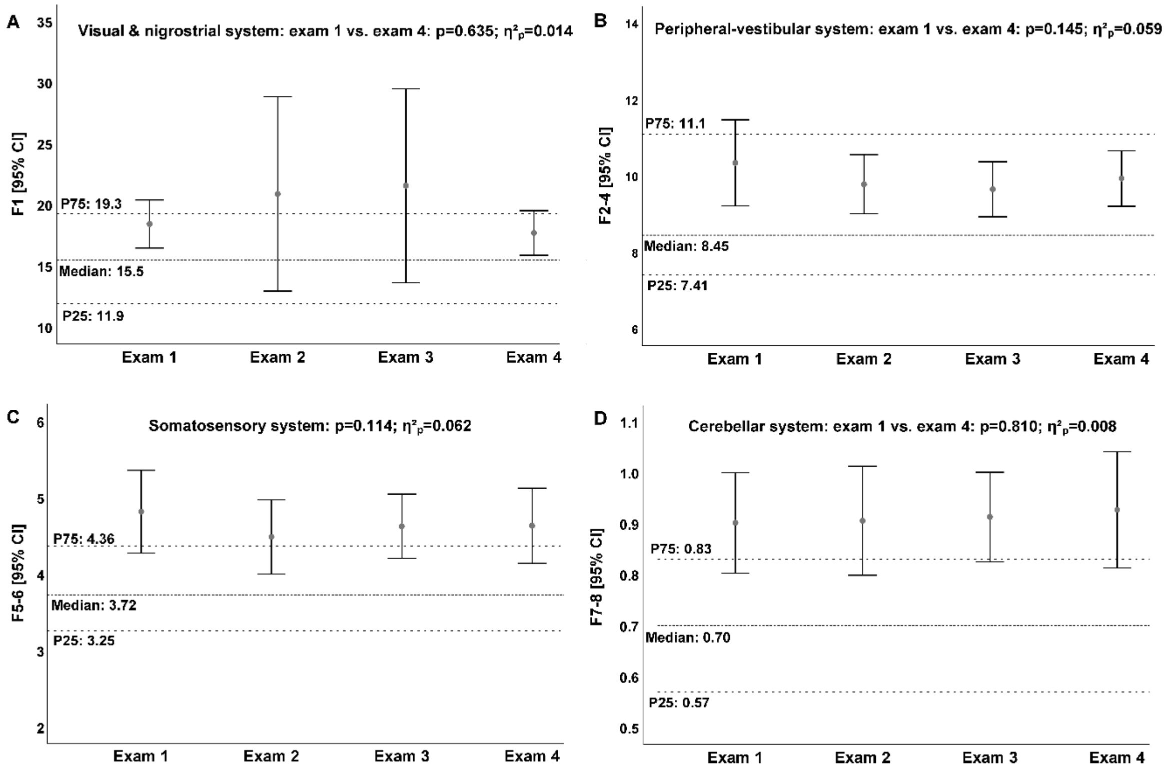

Figure 2. (**A**–**D**) Longitudinal changes of the postural subsystems compared with the matched reference sample based on percentile (P25, P50, P75) analysis. Total effects and relevant ($\eta_p^2 \geq 0.10$) partial effects are reported.

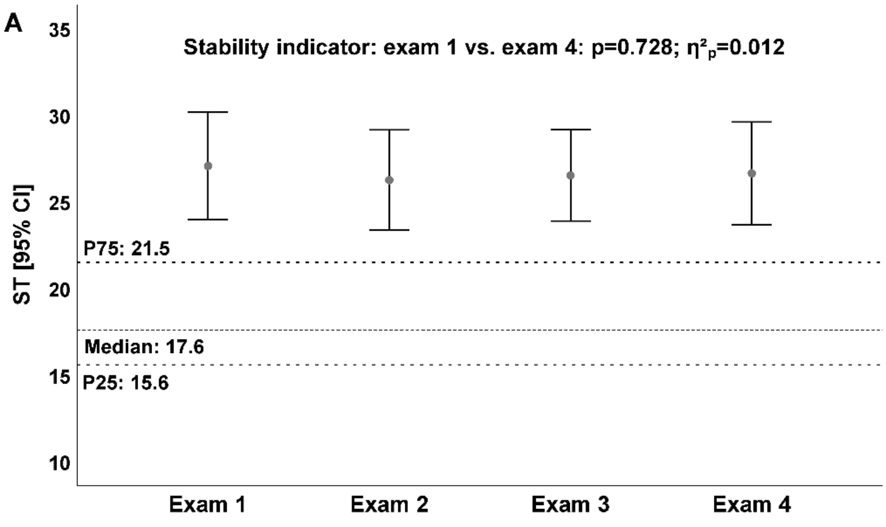

Figure 3. *Cont.*

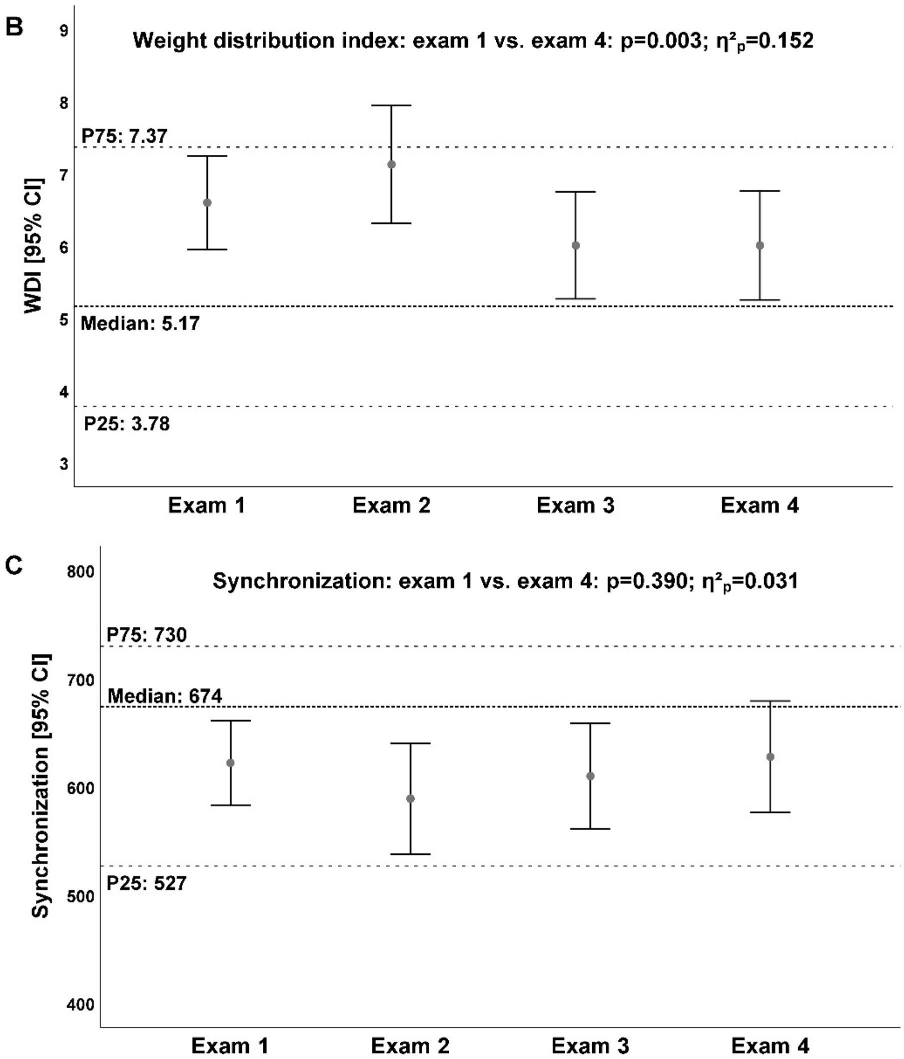

Figure 3. (**A**–**C**) Longitudinal changes of bilateral (stability indicator (ST) weight distribution index (WDI); synchronization (Synch)) posturographic parameters compared with the matched reference sample based on percentile (P25, P50, P75) analysis. Total effects and relevant ($\eta_p{}^2 \geq 0.10$) partial effects are reported.

The WDI was the parameter with the largest improvement ($\eta_p{}^2 = 0.152$) over the total time of the investigation. The HTO induced a short-term enhancement of the forefoot load (exam 1: 54.2 vs. exam 2: 57.2%, $\eta_p{}^2 = 0.272$; Table 3, Figure 4A) and the load of the unaffected side (left-sided load, injury on the right side: exam 1: 52.9 vs. exam 2: 54.5%; Table 3).

Table 3. Descriptive longitudinal comparison, analysis of variance and calculation of effect size (η_p^2) for unilateral Interactive Balance System (IBS) parameters depending on the side of injury/correction (left: n = 12; right: n = 20). Based on the comparison of adjacent examinations only significant differences are reported.

Parameter (%)	Examinations (Exam)				Variance Analysis		
	Exam 1	Exam 2	Exam 3	Exam 4	Comparison of Exam 1 vs. Exam 4		Comparison of Adjacent Exams
	Preoperative	6 Weeks Postoperative	12 Weeks Postoperative	6 Months Postoperative	p	η_π^2	η_π^2
Patients with left-sided injury (n = 12)							
Heel	**42.9 ± 5.78**	41.9 ± 6.11	42.8 ± 4.56	41.4 ± 4.87	0.594	0.051	3 vs. 4 (0.145)
Left	46.2 ± 4.25	43.1 ± 6.23	47.9 ± 3.68	**50.2 ± 3.28**	**0.001**	**0.547**	1 vs. 2 (0.219) 2 vs. 3 (0.636) 3 vs. 4 (0.486)
Patients with right-sided injury (n = 20)							
Heel	**45.8 ± 9.28**	42.8 ± 7.51	45.0 ± 7.99	43.3 ± 7.44	**0.052**	**0.131**	1 vs. 2 (0.272) 2 vs. 3 (0.122) 3 vs. 4 (0.118)
Left	52.9 ± 4.43	54.5 ± 5.42	51.7 ± 5.64	**50.8 ± 4.64**	**0.031**	**0.163**	2 vs. 3 (0.420)

Values are given as mean ± standard deviation. Heel: percentage of weight distribution forefoot vs. heel with description of heel loading; Left: percentage of weight distribution left vs. right with description of left side loading. Significance level: $p < 0.006$ or $\eta_p^2 \geq 0.10$. Significant differences and performance maxima marked in bold.

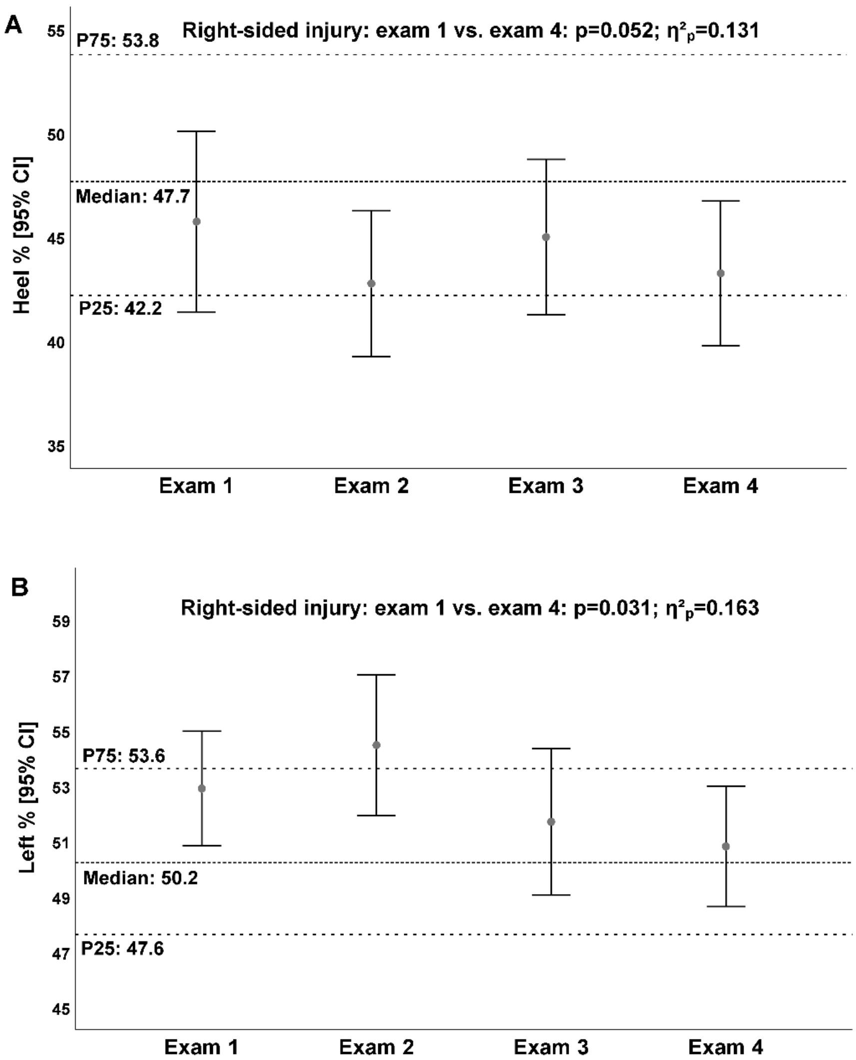

Figure 4. (**A**,**B**) Longitudinal changes of unilateral (heel, left) posturographic parameters compared with the matched reference sample based on percentile (P25, P50, P75) analysis for the patients with right-sided injury (n = 20). Total effects and relevant ($\eta_p^2 \geq 0.10$) partial effects are reported.

The highest time effects between adjacent examinations (patients with left-sided injury) were detected for the mediolateral weight distribution between exam 2 vs. exam 3 postoperatively ($\eta_p^2 = 0.636$) and exam 2 vs. exam 4 ($\eta_p^2 = 0.486$; Table 3). From exam 2 to exam 3, both subsamples showed the largest improvements (left-sided injury: 4.8%, $\eta_p^2 = 0.636$; right-sided injury: 2.8%, $\eta_p^2 = 0.420$) concerning the mediolateral weight distribution in the sense of a more powerful balance. Concerning postural regulation, no postural subsystems showed main effects for time (Table 2). There was only one partial time effect for the somatosensory subsystem between exam 1 (4.81 ± 1.50) and exam 2 (4.48 ± 1.35) detected ($\eta_p^2 = 0.152$).

3.3. Cross-Sectional Analysis—Comparison of HTO Patients with Matched Subjects

The comparison of HTO patients with matched individuals can be viewed in Tables 2 and 3, and in Figures 2–4. The largest difference (exam 3: $\eta_p^2 = 0.251$) to the matched sample was calculated for the stability indicator (ST, Figure 3A). The most (4) significant differences to the matched sample were also observed for ST (preoperative: $\eta_p^2 = 0.237$; exam 2: $\eta_p^2 = 0.215$; exam 3: $\eta_p^2 = 0.251$; exam 4: $\eta_p^2 = 0.229$; Table 2).

At six months post-HTO, the mediolateral load distribution moved on the "healthy" level (Figure 4B, Table 3). In contrast, the postural stability, measured by stability indicator was completely outside (above the percentile 75) the interquartile range of the healthy subjects (Figure 3A). The peripheral–vestibular system (Figure 2B) was the postural subsystem with the smallest difference to the median of the healthy subjects over the whole six-month period. Conversely, the activity of the cerebellar system (Figure 2D) was consistently above the 75th percentile of the healthy subjects for all examinations. Two significant differences (twelve weeks postoperative: $\eta_p^2 = 0.118$; six months postoperative: $\eta_p^2 = 0.103$) compared with the matched subjects were observed. The somatosensory system (Figure 2C) showed a similar pattern, but without significant differences at any examination.

3.4. Comparison of Patients Depending on the Side of Injury/HTO

A significant rise in mediolateral weight distribution was observed on the injured side after HTO (Table 3). This effect was much stronger in the patients with left-sided injury (exam 1 vs. 4: $\eta_p^2 = 0.547$ vs. $\eta_p^2 = 0.163$). Simultaneously, this was one of the largest observed main time effects. The left-side load in the HTO left-sided injury patients was the only parameter with significant changes in all three postoperative observation periods (Table 3). A peak was calculated between exam 2 and 3 ($\eta_p^2 = 0.636$). In contrast, the changes concerning anteroposterior weight distribution were much lower in both patient groups, especially for the left-sided HTO injury patients (exam 1 vs. 4: $\eta_p^2 = 0.051$ vs. 0.131). At six months post-operation, there was still an enhanced forefoot load (59 and 57%; Table 3) with the same difference (1.5%) between exam 1 and 4 for both patient groups.

3.5. Pain Assessment (VAS)

Pain perception over the entirety of the study (Figure 5) sharply decreased (main time effect: $p < 0.001$, $\eta_p^2 = 0.438$), especially from exam 1 to exam 2 (50.7 ± 20.0 vs. 33.9 ± 17.1; $\eta_p^2 = 0.339$).

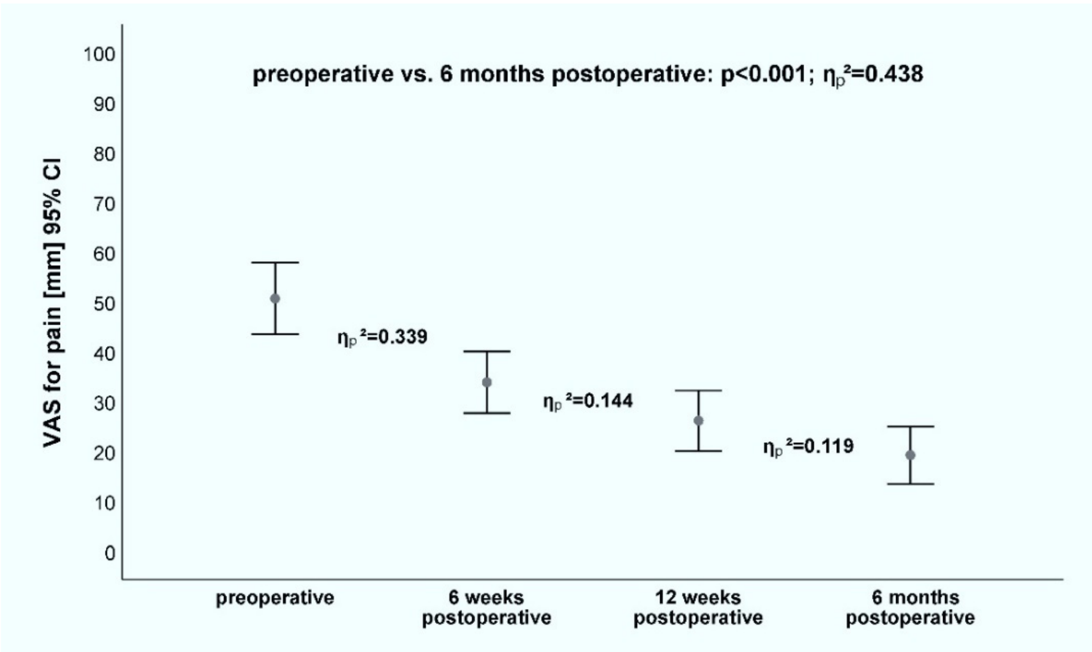

Figure 5. Descriptive, longitudinal changes for visual analogue scale (VAS), analysis of variance and calculation of effect size (η_p^2). Total effects and relevant ($\eta_p^2 \geq 0.10$) partial time effects are reported.

Significant changes were found for all investigated time intervals with the smallest significant difference displayed between exams 3 and 4 (26.2 ± 16.8 vs. 19.3 ± 16.0; $\eta_p^2 = 0.119$).

3.6. Quality of Life Assessment (SF-36)

With the exception of mental health ($\eta_p^2 = 0.016$), all other subscales showed significant improvements (Table 4).

Table 4. Descriptive longitudinal comparison, analysis of variance and calculation of effect size (η_p^2) for quality of life parameters. Based on the comparison of adjacent examinations only significant differences are reported.

Parameter	Examinations (Exam); n = 32				Variance Analysis		
	Exam 1 Preoperative	Exam 2 6 Weeks Postoperative	Exam 3 12 Weeks Postoperative	Exam 4 6 Months Postoperative	Comparison of Exam 1 vs. Exam 4 p	η_p^2	Comparison of Adjacent Exams η_p^2
Subscale							
Physical functioning	46.3 ± 21.9	45.3 ± 21.2	63.0 ± 20.9	75.8 ± 14.9	<0.001	0.451	2 vs. 3 (0.376) 3 vs. 4 (0.337)
Physical role functioning	43.0 ± 36.6	12.5 ± 23.8	57.0 ± 42.7	74.1 ± 30.3	<0.001	0.446	1 vs. 2 (0.386) 2 vs. 3 (0.500) 3 vs. 4 (0.221)
Bodily pain	31.7 ± 17.6	37.2 ± 14.7	57.3 ± 15.2	64.3 ± 16.3	<0.001	0.560	2 vs. 3 (0.562) 3 vs. 4 (0.212)
General health perception	57.4 ± 19.2	61.4 ± 18.9	68.2 ± 17.2	66.8 ± 15.9	0.007	0.134	2 vs. 3 (0.120)
Vitality	52.2 ± 18.3	50.9 ± 17.8	64.5 ± 18.1	65.8 ± 17.2	<0.001	0.267	2 vs. 3 (0.369)
Social role functioning	78.9 ± 27.6	71.1 ± 24.1	83.2 ± 24.9	86.3 ± 23.4	0.003	0.151	2 vs. 3 (0.226)
Emotional role functioning	78.1 ± 37.5	59.4 ± 44.6	78.3 ± 36.3	85.0 ± 29.6	0.008	0.126	1 vs. 2 (0.188) 2 vs. 3 (0.154)
Mental health	74.0 ± 15.9	78.4 ± 16.6	75.9 ± 23.9	77.5 ± 23.1	0.646	0.016	-
Total score							
physical health component summary score	31.4 ± 8.16	29.8 ± 7.22	40.5 ± 8.28	45.0 ± 6.36	<0.001	0.573	2 vs. 3 (0.569) 3 vs. 4 (0.365)
mental health component summary score	55.0 ± 11.4	53.5 ± 11.3	54.4 ± 11.1	53.6 ± 11.1	0.804	0.010	-

Values are given as mean ± standard deviation. Significance level: $p < 0.006$ or $\eta_p^2 \geq 0.10$. Significant differences and performance maxima marked in bold.

The smallest significant change was calculated for emotional role functioning (η_p^2 = 0.126). In contrast, bodily pain displayed the largest improvement (η_p^2 = 0.560), especially between exams 2 and 3 (37.2 ± 14.7 vs. 57.3 ± 15.2; η_p^2 = 0.562). The physical role functioning was the only subscale with significant improvements between all examinations. Similar to bodily pain, the largest change was observed between exams 2 and 3 (12.5 ± 23.8 vs. 57.0 ± 42.7; η_p^2 = 0.500). After a postoperative period of six weeks, the standard deviation was clearly higher than the mean (coefficient of variation: 190%). It was the only quality of life parameter with a coefficient of variation above 100% at any examination.

4. Discussion

The primary objective of this prospective, longitudinal (preoperative to six months postoperative) cohort study was to evaluate the effect of HTO and subsequent rehabilitation on load distribution postural stability and postural regulation. Regarding posturography, the cross-sectional comparison with asymptomatic matched individuals was also performed. Additionally, the parameters quality of life and pain perception were also investigated.

Our results supported hypothesis one indicating that the HTO leads to a strong weight relief of the injured side. Improvement of the mediolateral weight distribution needs at least a six-month postoperative period. After medial knee compartmental OA and HTO postural stability is strongly reduced (hypothesis two). The largest posturographic changes during the six-month investigation period were calculated for weight distribution (η_p^2 = 0.152). As expected, the mediolateral weight distribution (left-sided injury: η_p^2 = 0.547; right-sided injury: η_p^2 = 0.163) showed the largest improvements. Consistently, the largest differences (exam 1–4: 29–33%) and highest activity (hyperactivity/compensation) compared with the matched asymptomatic subjects (reference: median), were observed in cerebellar system after HTO (hypothesis three). A similar hyperactive pattern was found for the visual and nigrostriatal system during exam 2 (35%) and exam 3 (39%). At exam 4, these postural subsystems showed the smallest difference (14%) of all postural subsystems according to the median of the matched subjects.

The peripheral–vestibular system consistently showed the smallest differences (exam 1–4: 14–22%) compared to the matched subjects and lowest activity directly (exam 2: 16%) after HTO. In contrast to the postural stability and regulation, pain perception (main time effect: η_p^2 = 0.438) and the physical health component of quality of life η_p^2 = 0.573) were strongly improved following HTO and subsequent rehabilitation. In particular, the subscales bodily pain (η_p^2 = 0.560), physical functioning (η_p^2 = 0.451) and physical role functioning (η_p^2 = 0.446) showed the largest longitudinal improvements (hypothesis four).

4.1. Weight Distribution and Postural Stability

The comparability of our results with previous studies is limited because we used different assessments to measure postural stability. For example, Hunt et al. [14,36] used the single leg stand on a force platform to judge the balance of patients with OA (n = 49) prior to and 12 months following medial opening wedge HTO. In line with our longitudinal study design, they also found only small ($d < 0.34$) and not significant ($p > 0.05$) changes regarding center of pressure and standing balance following HTO. As in our study, these patients showed a reduction in pain as quantified by the WOMAC despite no changes in standing balance [14]. Hunt et al. [36] found that the amount of varus malalignment was inversely related to single-legged standing balance. Presumably, neuromuscular control is reduced in the presence of this malalignment. The authors discussed a reduced joint innervation or muscle reflexes as possible causes [37]. It seems, that asymptomatic subjects with varus alignment exhibit more changed postural control strategies than subjects with neutral alignment [38]. Kim et al. [39] also used the IBS and investigated 80 patients with primary OA, classified by the Kellgren–Lawrence score (mild vs. moderate to severe) and 40 age-matched controls. These authors detected a higher postural sway of the moderate to severe group compared to those of the mild or control groups.

4.2. Postural Regulation and Subsystems

Kim et al. [39] showed a larger amount of instability in their moderate-to-severe primary OA group than the mild or control groups except for the somatosensory and cerebellar systems. They deduced that moderate-to-severe patients with knee OA depend on their eyesight in order to compensate for their postural instability. The calculated values for all frequency bands were much higher comparable with this study and Bartels et al. [16].

Following ACL rupture and surgical reconstruction and consistent with our study, Bartels et al. [16] observed the largest reductions of postural subsystems for the somatosensory (consistently below the healthy median reference) and cerebellar systems. However, in contrast to Bartels et al. [16] we detected a hyperactivity in both systems (consistently above the healthy interquartile range; Figure 2C,D) and not a suppression, especially at six-months post-operation. Obviously, these types of lower limb surgeries would have completely different effects concerning postural subsystems. The change of somatosensory information, potentially caused by mechanoreceptor damage (e.g., HTO surgery), may subsequently lead to a reduction of postural stability and regulation [40]. Both investigations are examples and proofs for the neuroplasticity of biological systems and the model of selective compensatory optimization. For example, the relation between the somatosensory system and the spinocerebellum system, which is responsible for processing the afferent (somatosensory) information is very close. The relationship between the peripheral–vestibular system and the vestibulocerebellum system is comparable. In this context, the hyperactive effects are caused by reduced activity of other postural systems, in this case particularly the peripheral-vestibular system (consistently below the healthy percentile 75; Figure 2B). Brandt et al. [41] demonstrated that knee osteoarthritis (OA) causes changes not only in the tissues within the articular cavity, but also the ligaments, tendons, and periarticular tissues including the muscles. Furthermore, patients with knee OA have deficiencies in the number of sensory receptors and therefore their proprioception compared to similar age controls Barrett et al. [42].

At six-months post-HTO, postural regulation returned to an asymptomatic level for mediolateral weight distribution. The cross-sectional comparison to asymptomatic subjects at all examinations showed that OA and HTO led to hyperactivity of the cerebellar and somatosensory systems and postural instability. Obviously, the subsequent rehabilitation was not able to improve postural regulation and stability. This investigation provides further insight into the underlying mechanisms of postural regulation and in the understanding of the interaction of postural subsystems. Future research examining postural stability after one- and two-year postoperative periods will provide a subsequent midterm and long-term evaluation of surgery and rehabilitation. It is possible that improvements in postural stability and regulation need longer than six-months to occur. In relation to other studies [17,49], we wanted to establish a more holistic approach instead of the frequently used isolated orthopedic view (flexibility, strength, pain).

4.3. Clinical Outcomes

Previous research has shown the effectiveness of uni-compartmental arthrosis for joint-preservation. Floerkemeier et al. [43] described a multicenter study with a large patient population (n = 533). Of these patients, 80% were very satisfied with the result of the surgery, in relation to knee pain and function. Insall et al. [44] reported that over a 10-year period, until conversion to a prosthesis, HTO should be considered for more physically active patients and has better results with advanced implants. According to the Finnish National Hospital Discharge Register (NHDR), the survival rate for 3195 knee-related reconversion osteotomies was 89% over 5 years and 73% over 10 years [45]. Naudie et al. [46] reported slightly lower survival rates of 73% after 5 years, 51% after ten years, 39% after 15 years and 30% after 20 years.

4.4. Pain Situation and Quality of Life

Van der Woude et al. [6] compared the efficacy of knee joint distraction (n = 23) and HTO (n = 46). In line with our results, these authors found significant improvements for the HTO group in the VAS pain score ($p = 0.006$) and physical component of SF 36 ($p = 0.024$) one year after surgery. Bastard et al. [13] evaluated return to sports and quality of life after HTO in athletic patients less than 60 years of age. The patients had the same age (mean age: 55.6 years) as our patients (mean age: 55.3 years) and in line with our results, they observed a significant improvement ($p = 0.01$) in quality of life pre-operatively (65%) compared with one year postoperatively (73%). In this time interval, the SF-36 physical sub-score also increased significantly ($p = 0.02$) from 59 (55–63) to 67 (58–72). However, the level of quality of life was consistently higher than in our investigation (from 59 to 67 vs. 30 to 45). However, this comparison is only valid for the preoperative evaluation because the postoperative examination is (still) different (one-year vs. six-months). Bonnin et al. [7] reported a similar level of quality of life (SF-12 physical score: 53.6 ± 9.7) for a non-selected population of HTO patients (closing-wedge HTO: n = 88; opening-wedge HTO: n = 51) as in our study to exam 4 (45.0 ± 6.36). Ihle et al. [34] examined the health-related quality of life (assessment: SF-36) in patients (n = 120) after HTO. In line with our study, they also found significantly longitudinal (after 6, 12 and 18 months postoperatively) improvements in the physical score ($p < 0.001$) in contrast to small changes in the mental score of the SF-36 ($p = 0.360$). The amount of improvement (13.6 vs. 9.3) over the time (six months) in the physical score was much higher in our study compared those of Ihle et al. [34]. Saier et al. [47] also observed a significant increase in health related quality of life (SF-36) and decrease in pain (VAS; $p < 0.001$; $\eta_p^2 = 0.4$) among patients (n = 64) after open-wedge high tibial osteotomy across the same time period of six months. The improvements in the physical score ($p < 0.001$; $\eta_p^2 = 0.4$) of the SF-36 were also much higher than in the mental score ($p = 0.008$, $\eta_p^2 = 0.1$). Webster and Feller [48] reported an increase in the physical scores of patients (n = 414) with knee OA before surgery and at a minimum of 12 months following knee replacement (33.6 to 45.6). In contrast, the change regarding the mental score was clearly smaller (52.2 to 55.1). We hope that our future investigations (one year and two years postoperative) will provide further insight into the long-term outcomes after HTO and rehabilitation. In summary, the HTO and the subsequent rehabilitation led to a significant improvement of the physical component of the quality of life. However, the mental part of the quality of life remained unaffected.

4.5. Limitations

Our prospective cohort study has some limitations worth noting. First, we had a relatively small sample size (n = 32). Initially, we recruited 37 patients. In the interest of a homogeneous sample (only men to avoid sex effects), we decided to eliminate three women (exam 2: n = 34). Between exams 3 and 4, two additional patients dropped out of the study, because they did not want to continue (exam 4: n = 32).

Although our patients conducted a standardized rehabilitation program (Table A1), a limiting factor in this examination was that the investigators had no direct influence on the rehabilitation process. Therefore, we are not able to guarantee that each protocol was realized completely as recommended. In addition, there was no uniform standardized treatment 16 weeks after surgery as the patients were discharged from clinical surveillance. Comparable to the study design by Bartels et al. [16], the longitudinal comparison is limited due to the different temporal durations between the four examinations (e.g., six weeks, twelve weeks, six months). Consequently, the longest time interval (twelve weeks) from exam 3 to 4 was supposed to have the highest potential for changes.

In regards to the time periods of the postoperative examinations, there were small differences compared to the targeted time points: exam 1 (preoperative) occurred 6.38 ± 10.2 (0–40) days preoperatively, exam 2 (six weeks) occurred 41.8 ± 5.11 (33–53) days postoperatively, exam 3 (twelve weeks) occurred 88.3 ± 20.3 (74–193) days postoperatively, and exam 4 (six-months) occurred 182 ± 12.1 (137–203) days postoperatively.

Essentially, we were not able to guarantee a precise realization of the timeline. Preoperatively, 69% (n = 22) of the patients were examined between 0 and 5 prior to surgery. Based on a time interval of three days around the ideal time point, 66% (n = 21, exam 2), 44% (n = 14, exam 3) and 31% (n = 10, exam 4) of the patients were tested in this time window.

5. Conclusions and Clinical Implications

From a clinical perspective, the findings of this investigation indicate that HTO patients do not present with improvements in postural performance following surgery and rehabilitation. Therefore, similar to ACL surgery and rehabilitation [16], the rehabilitation program should implement unexpected disturbances in order to improve feedforward mechanisms. This could contribute to improvements in the somatosensory and cerebellar systems. For example, Bartels et al. [49] described and examined a rehabilitation concept using unexpected cues that cause a response time of less than 200 ms five-months after an ACL reconstruction. The study results identified the IBS as a scientific evaluation and a useful posturographic assessment in terms of HTO surgery and following rehabilitation. The center of pressure measurement using IBS allows for a functional distinction in postural stability of HTO patients and asymptomatic subjects. Based on these study results and our extensive experiences, the IBS might support the work of physicians and physical therapists and adjust rehabilitation demands in a more precise and evidence-based way.

The outcomes of this investigation indicate that patients with medial tibiofemoral osteoarthrosis have deficits in postural stability and regulation. HTO and rehabilitation is not able to generate substantial improvements in these parameters during the observed period of six months. Sole overload of the injured side foot decreased significantly over the six months after HTO. In contrast, pain perception and quality of life (physical component) significantly improved after HTO and rehabilitation.

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Appendix A

Table A1. Phases (Ph) of rehabilitation after HTO.

Ph	Week	Goals and Content
1	1	• *<u>Aim:</u> pain relief, no effusion, pain free Range of Motion (ROM)* • Immediately: postoperative treatment with cryotherapy • Constant support with an orthopedic splint (Listra) • First day: removal of the drainage • Manual lymphatic drainage (2–3 times per week) • Partial weight bearing with crutches (20 kg) • Fourth day: change of bandages
2	2	• *<u>Aim:</u> pain free full ROM, partial weight bearing, safe muscular stabilization of knee joint* • Suture removal and change of bandages • Manual lymphatic drainage (2–3 times per week) • Partial weight bearing with crutches (20 kg) • Isometric exercises with special regard to knee extension ROM

Table A1. *Cont.*

Ph	Week	Goals and Content
3	3–10	• *Aim: pain free full ROM, pain-adapted full weight bearing, safe muscular stabilization of knee joint* • Fourth week: physical therapy (strength and endurance) • X-ray • Intense rehabilitation in clinic or institution if desired by patient
4	11–15	• *Aim: recovery of full general function* • X-ray if necessary
5	16st week and later	• *Aim: Restoration of full working or sports ability* • Patient receives instructions/recommendations for further independent training (without therapist) related to their specific sport or occupation • Patient should return to work or competitive sport after 4–6 months

References

1. Felson, D.T.; Naimark, A.; Anderson, J.; Kazis, L.; Castelli, W.; Meenan, R.F. The prevalence of knee osteoarthritis in the elderly. The Framingham osteoarthritis study. *Arthritis Rheum.* **1987**, *30*, 914–918. [CrossRef] [PubMed]
2. Kurtz, S.M.; Lau, E.; Ong, K.; Zhao, K.; Kelly, M.; Bozic, K.J. Future young patient demand for primary and revision joint replacement: National projections from 2010 to 2030. *Clin. Orthop. Relat. Res.* **2009**, *467*, 2606–2612. [CrossRef] [PubMed]
3. Lobenhoffer, P.; Agneskirchner, J.D. Improvements in surgical technique of valgus high tibial osteotomy. *Knee Surg. Sport. Traumatol. Arthrosc.* **2003**, *11*, 132–138. [CrossRef]
4. Lobenhofffer, P.; Agneskirchner, J.; Zoch, W. Open valgus alignment osteotomy of the proximal tibia with fixation by medial plate fixator. *Orthopade* **2004**, *33*, 153–160. [CrossRef]
5. Bode, G.; Schmal, H.; Pestka, J.M.; Ogon, P.; Südkamp, N.P.; Niemeyer, P. A non-randomized controlled clinical trial on autologous chondrocyte implantation (ACI) in cartilage defects of the medial femoral condyle with or without high tibial osteotomy in patients with varus deformity of less than 5°. *Arch. Orthop. Trauma Surg.* **2013**, *133*, 43–49. [CrossRef]
6. Van der Woude, J.A.D.; Wiegant, K.; van Heerwaarden, R.J.; Spruijt, S.; van Roermund, P.M.; Custers, R.J.H.; Mastberger, S.C.; Lafeber, F.P.J.G. Knee joint distraction compared with high tibial osteotomy: A randomized controlled trial. *Knee Surg. Sport. Traumatol. Arthrosc.* **2017**, *25*, 876–886. [CrossRef]
7. Bonnin, M.P.; Laurent, J.R.; Zadegan, F.; Badet, R.; Pooler Archbold, H.A.; Servien, E. Can patients really participate in sport after high tibial osteotomy? *Knee Surg. Sport. Traumatol. Arthrosc.* **2013**, *21*, 64–73. [CrossRef]
8. Spahn, G.; Klinger, H.M.; Harth, P.; Hofmann, G.O. Cartilage regeneration after high tibial osteotomy. Results of an arthroscopic study. *Z. Orthop. Unf.* **2012**, *150*, 272–279. [CrossRef]
9. Jung, W.H.; Takeuchi, R.; Chun, C.W.; Lee, J.S.; Ha, J.H.; Kim, J.H.; Jeong, J.H. Second-look arthroscopic assessment of cartilage regeneration after medial opening-wedge high tibial osteotomy. *Arthroscopy* **2014**, *30*, 72–79. [CrossRef]
10. Koh, Y.G.; Kwon, O.R.; Kim, Y.S.; Choi, Y.J. Comparative outcomes of open-wedge high tibial osteotomy with platelet-rich plasma alone or in combination with mesenchymal stem cell treatment: A prospective study. *Arthroscopy* **2014**, *30*, 1453–1460. [CrossRef]
11. Jung, W.H.; Takeuchi, R.; Chun, C.W.; Lee, J.S.; Jeong, J.H. Comparison of results of medial opening-wedge high tibial osteotomy with and without subchondral drilling. *Arthroscopy* **2015**, *31*, 673–679. [CrossRef] [PubMed]
12. Wiegant, K.; van Heerwaarden, R.J.; van der Woude, J.A.D.; Custers, R.J.H.; Emans, P.J.; Kuchuk, N.O.; Mastbergen, S.C.; Lafeber, F.P.J.G. Knee joint distraction as an alternative surgical procedure for patients with osteoarthritis considered for high tibial osteotomy or for a total knee prosthesis: Rationale and design of two randomized controlled trials. *Int. J. Orthop.* **2015**, *2*, 353–360. [CrossRef]
13. Bastard, C.; Mirouse, G.; Potage, D.; Silbert, H.; Roubineau, F.; Hernigou, C.H.; Flouzat-Lachaniette, C.H. Return to sports and quality of life after high tibial osteotomy in patients under 60 years of age. *Orthop. Traumatol. Surg. Res.* **2017**, *103*, 1189–1191. [CrossRef] [PubMed]

14. Hunt, M.A.; Birmingham, T.B.; Jones, I.C.; Vandervoort, A.A.; Giffin, J.R. Effect of tibial re-alignment surgery on single leg standing balance in patients with knee osteoarthritis. *Clin. Biomech.* **2009**, *24*, 693–696. [CrossRef]
15. Zhang, Z.; Lion, A.; Chary-Valckenaere, I.; Loeuille, D.; Rat, A.C.; Paysant, J.; Perrin, P.P. Diurnal variation on balance control in patients with symptomatic knee osteoarthritis. *Arch Gerontol. Geriatr.* **2015**, *61*, 109–114. [CrossRef] [PubMed]
16. Bartels, T.; Brehme, K.; Pyschik, M.; Pollak, R.; Schaffrath, N.; Schulze, S.; Delank, K.S.; Laudner, K.G.; Schwesig, R. Postural stability and regulation before and after anterior cruciate ligament reconstruction—A two-years longitudinal study. *Phys. Ther. Sport* **2019**, *38*, 49–58. [CrossRef]
17. Bartels, T.; Brehme, K.; Pyschik, M.; Schulze, S.; Delank, K.S.; Fieseler, G.; Laudner, K.G.; Hermassi, S.; Schwesig, R. Pre- and postoperative postural regulation following anterior cruciate ligament reconstruction. *J. Exerc. Rehab.* **2018**, *14*, 143–151. [CrossRef]
18. Miniaci, A.; Ballmer, F.T.; Ballmer, P.M.; Jakob, R.P. Proximal tibial osteotomy. A new fixation device. *Clin. Orthop. Relat. Res.* **1989**, *246*, 250–259.
19. Schwesig, R.; Fischer, D.; Kluttig, A. Are there changes in postural regulation across the lifespan? *Somatosens. Mot. Res.* **2013**, *30*, 167–174. [CrossRef]
20. Friedrich, M.; Grein, H.J.; Wicher, C.; Schuetze, J.; Müller, A.; Lauenroth, A.; Hottenrott, K.; Schwesig, R. Influence of pathologic and simulated visual dysfunctions on the postural system. *Exp. Brain Res.* **2008**, *186*, 305–314. [CrossRef]
21. Schwesig, R.; Becker, S.; Lauenroth, A.; Kluttig, A.; Leuchte, S.; Esperer, H.D. A novel posturographic method to differentiate sway patterns of patients with Parkinson's disease from patients with cerebellar ataxia. *Biomed. Tech.* **2009**, *54*, 347–356. [CrossRef] [PubMed]
22. Schwesig, R.; Goldich, Y.; Hahn, A.; Müller, A.; Kohen-Raz, R.; Kluttig, A.; Morad, Y. Postural control in subjects with visual impairment. *Eur. J. Ophthalmol.* **2011**, *21*, 303–309. [CrossRef] [PubMed]
23. Reinhardt, L.; Heilmann, F.; Teicher, M.; Wollny, R.; Lauenroth, A.; Delank, K.S.; Schwesig, R.; Wollny, R.; Kurz, E. Comparison of posturographic outcomes between two different devices. *J. Biomech.* **2019**, *86*, 218–224. [CrossRef] [PubMed]
24. Schwesig, R.; Becker, S.; Fischer, D. Intraobserver reliability of posturography in healthy subjects. *Somatosens. Mot. Res.* **2014**, *31*, 16–22. [CrossRef] [PubMed]
25. Schwesig, R.; Fischer, D.; Becker, S.; Lauenroth, A. Intraobserver reliability of posturography in patients with vestibular neuritis. *Somatosens. Mot. Res.* **2014**, *31*, 28–34. [CrossRef] [PubMed]
26. Schwesig, R.; Hollstein, L.; Plontke, S.K.; Delank, K.S.; Fieseler, G.; Rahne, T. Comparison of intraobserver single-task reliabilities of the Interactive Balance System (IBS) and Vertiguard in asymptomatic subjects. *Somatosens. Mot. Res.* **2017**, *34*, 9–14. [CrossRef]
27. Seiwerth, I.; Jonen, J.; Rahne, T.; Schwesig, R.; Lauenroth, A.; Hullar, T.; Plontke, S.K. Influence of hearing on vestibulospinal control in healthy subjects. *HNO* **2018**, *66*, 590–597. [CrossRef]
28. Seiwerth, I.; Jonen, J.; Rahne, T.; Lauenroth, A.; Hullar, T.; Plontke, S.; Schwesig, R. Postural regulation and stability with acoustic input in normal hearing subjects. *HNO* **2020**, *68*, 100–105. [CrossRef]
29. Rat, A.C.; Coste, J.; Pouchot, J.; Baumann, M.; Spitz, E.; Retel-Rude, N.; Le Quintrec, J.S.; Dumont-Fischer, D.; Guillemin, F. OAKHQOL: A new instrument to measure quality of life in knee and hip osteoarthritis. *J. Clin. Epidemiol.* **2005**, *58*, 47–55. [CrossRef]
30. Ware, J.E., Jr.; Sherbourne, C.D. The MOS 36-item short-form health survey (SF-36). Conceptual framework and item selection. *Med. Care* **1992**, *30*, 473–483. [CrossRef]
31. Bullinger, M. German translation and psychometric testing of the SF-36 Health Survey: Preliminary results from the IQOLA Project. International Quality of Life Assessment. *Soc. Sci. Med.* **1995**, *41*, 1359–1366. [CrossRef]
32. Mc Horney, C.A.; Ware, J.E., Jr.; Lu, J.F.; Sherbourne, C.D. The MOS 36-item Short-Form Health Survey (SF-36): III. Tests of data quality, scaling assumptions, and reliability across diverse patient groups. *Med. Care* **1994**, *32*, 40–66. [CrossRef] [PubMed]
33. Bullinger, M.; Alonso, J.; Apolone, G.; Leplege, A.; Sullivan, M.; Wood-Dauphinee, S. Translating health status questionnaires and evaluating their quality: The IQOLA Project approach. International Quality of Life Assessment. *J. Clin. Epidemiol.* **1998**, *51*, 913–923. [CrossRef]

34. Ihle, C.; Ateschrang, A.; Grünwald, L.; Stöckle, U.; Saier, T.; Schröter, S. Health-related quality of life and clinical outcomes following medial open wedge high tibial osteotomy: A prospective study. *BMC Musculoskelet. Disord.* **2016**, *17*, 215. [CrossRef] [PubMed]
35. Richardson, J.T.E. Eta squared and partial eta squared as measures of effect size in educational research. *Educ. Res. Rev.* **2011**, *6*, 135–147. [CrossRef]
36. Hunt, M.A.; McManus, F.J.; Hinman, R.S.; Bennell, K.L. Predictors of single-leg standing balance in individuals with medial knee osteoarthritis. *Arthritis Care Res.* **2010**, *62*, 496–500. [CrossRef] [PubMed]
37. Salo, P. The role of joint innervation in the pathogenesis of arthritis. *Can. J. Surg.* **1999**, *42*, 91–100. [PubMed]
38. Nyland, J.; Smith, S.; Beickman, K.; Armsey, T.; Caborn, D. Frontal plane knee angle affects dynamic postural control strategy during unilateral stance. *Med. Sci. Sport. Exerc.* **2001**, *34*, 1150–1157. [CrossRef]
39. Kim, H.S.; Yun, D.H.; Yoo, S.D.; Kim, D.H.; Jeong, J.S.; Yun, J.S.; Hwang, D.G.; Jung, P.K.; Choi, S.H. Balance control and knee osteoarthritis severity. *Ann. Rehabil. Med.* **2011**, *35*, 701–709. [CrossRef]
40. Lehmann, T.; Paschen, L.; Baumeister, J. Single-leg assessment of postural stability after anterior cruciate ligament injury: A systematic review and metaanalysis. *Sport. Med. Open* **2017**, *3*, 32. [CrossRef]
41. Brandt, K.D.; Dieppe, P.; Radin, E.L. Etiopathogenesis of osteoarthritis. *Rheum. Dis. Clin. N. Am.* **2008**, *34*, 531–539. [CrossRef] [PubMed]
42. Barrett, D.S.; Cobb, A.G.; Bentley, G. Joint proprioception in normal, osteoarthritic and replaced knees. *J. Bone Jt. Surg. Br.* **1991**, *73*, 53–56. [CrossRef]
43. Floerkemeier, S.; Staubli, A.E.; Schröter, S.; Goldhahn, S.; Lobenhoffer, P. Outcome after high tibial open-wedge osteotomy: A retrospective evaluation of 533 patients. *Knee Surg. Sport. Traumatol. Arthrosc.* **2013**, *21*, 170–180. [CrossRef] [PubMed]
44. Insall, J.N.; Joseph, D.M.; Msika, C. High tibial osteotomy for varus gonarthrosis. A long-term follow-up study. *J. Bone Jt. Surg. Am.* **1984**, *66*, 1040–1048. [CrossRef]
45. Niinimäki, T.T.; Eskelinen, A.; Mann, B.S.; Junnila, M.; Ohtonen, P.; Leppilahti, J. Survivorship of high tibial osteotomy in the treatment of osteoarthritis of the knee. *J. Bone Jt. Surg. Br.* **2012**, *94*, 1517–1521. [CrossRef]
46. Naudie, D.; Bourne, R.B.; Rorabeck, C.H.; Bourne, T.J. The Install award: Survivorship of the high tibial valgus osteotomy. *Clin. Orthop. Relat. Res.* **1999**, *367*, 18–27. [CrossRef]
47. Saier, T.; Minzlaff, P.; Feucht, M.J.; Lämmle, L.; Burghoff, M.; Ihle, C.; Imhoff, A.B.; Hinterwimmer, S. Health-related quality of life after open-wedge high tibial osteotomy. *Knee Surg. Sport. Traumatol. Arthrosc.* **2017**, *25*, 934–942. [CrossRef]
48. Webster, K.E.; Feller, J.A. Comparison of the short form-12 (SF-12) health status questionnaire with the SF-36 in patients with knee osteoarthritis who have replacement surgery. *Knee Surg. Sport. Traumatol. Arthrosc.* **2016**, *24*, 2620–2626. [CrossRef]
49. Bartels, T.; Proeger, S.; Brehme, K.; Pyschik, M.; Delank, K.S.; Schulze, S.; Schwesig, R.; Fieseler, G. The SpeedCourt system in rehabilitation after reconstruction surgery of the anterior cruciate ligament (ACL). *Arch. Orthop. Trauma Surg.* **2016**, *136*, 957–966. [CrossRef]