Total Knee Arthroplasty: Stair Negotiation and Gait

Whole Body Gait Function during Stair Ascending and Level Walking in Patients Following Total Knee Arthroplasty

Abstract

The ability to climb stairs is a highly demanding task for the musculoskeletal system, and gait adaptations after total knee arthroplasty (TKA) might be more pronounced during stair climbing than during level walking. The purpose of this study was to compare full body kinematics and kinetics between patients with good functioning TKA and a healthy control group during stair ascending and level walking.

Eighteen patients after TKA (67.8 ± 8.1 yrs) and 20 age-matched healthy controls (66.1 ± 6.4 yrs) participated in this study. Full body kinematic and kinetic data was collected during stair ascending and level walking.

Patients after TKA showed differences in sagittal plane knee moments during both stair ascending and level walking compared to the controls. The hip of the patients was more externally rotated in both conditions ($p<0.001$), although there were no differences in the passive range of motion ($p=0.630$). The trunk angles only showed a few deviations between patients and controls. Differences between patients and controls were found more often during level walking than during stair ascending.

The study shows that considering adjacent joints gives more additional information for treatment recommendations than the additional analysis of the trunk when comparing patients after TKA to healthy seniors. To reduce the higher knee flexion moment during stair ascending in patients, we recommend the strengthening of the calf muscles. It seems that stair ascending does not provide additional information to guide actual treatment recommendations compared to level walking alone.

Keywords: Stair ascending; Gait analysis; Total knee arthroplasty; Plantar flexor weakness; Gait adaption

Introduction

Total knee arthroplasty (TKA) is the standard treatment for advanced symptomatic knee osteoarthritis with the goal of a pain-free joint to perform daily activities such as level walking or stair climbing. However, the functional outcome and patient satisfaction after TKA surgery is less favorable than after a total hip replacement in a significant proportion of TKA patients [1]. Even modern knee designs never fully restore the anatomy of the natural knee. The anterior cruciate ligament is usually resected and the geometry of knee prostheses does not completely match that of the natural knee. In addition, gait adaptations to reduce the pain in the years prior to the TKA may have already manifested. For instance, a systematic review of studies on gait after knee arthroplasty showed that only 20% of patients walked with a normal biphasic knee flexion-extension moment [2].

Compared to level walking, healthy people generate higher loads [3,4], joint moments and power [4] and activate their flexor-extensor muscles more when ascending stairs [5,6]. Especially older people might perform closer to their maximum capacity when climbing stairs [7]. Data from instrumented total knee prostheses showed that knee flexion moments during stair walking is 30% greater than those for level walking [8]. Hence, gait adaptations to total knee arthroplasty (TKA) are presumably more prevalent for stair climbing than for level walking.

Studies have shown that trunk motion influences knee moments during level walking in healthy subjects [9] and Lin et al. reported a forward leaning of the trunk for TKA-patients during walking to compensate for the reduced quadriceps strength [10]. Patients with knee osteoarthritis also walked with a more bent trunk during stair walking to reduce the external knee flexion moment [11]. In contrast a recent study from Bjerke et al. did not find differences in trunk leaning for TKA-patients with quadriceps weakness during stair ascending [12]. The patients measured with assessed slower quadriceps and hamstring strength from Bjerke et al. walked with a slower walking velocity to compensate for the reduced force, but they did not analyze the joint kinetics [12]. Hence, there are different possible gait adaptations to TKA which are likely not limited to the lower extremity but also include changes in upper body kinematics. However, most studies have focused on lower body kinematics and kinetics and frontal knee moments in people with knee osteoarthritis or patients after TKA [13-15]. To the best of our knowledge comprehensive information on ambulatory changes including joint kinetics and joint kinematics of the lower and upper body in patients with good physical function after TKA during walking and stair ascending is lacking.

The purpose of this study was to provide full body kinematics and kinetics for level and stair walking in patients with good physical function after TKA. A further objective of the study was to test the hypothesis that differences in trunk kinematics and lower extremity kinematics and kinetics between patients with TKA and age-matched control subjects become more evident when comparing data from stair ascending than data from level walking.

Methods

Participants

Eighteen patients (8 women, 10 men) after total knee arthroplasty (Low-Contact-Stress implant LCS® Complete™; DePuy, Johnson & Johnson company, Warsaw, USA) were included in the study (Table 1). All patients were satisfied with the procedure and showed good outcome scores. The gait analysis was performed 1.9 ± 1.2 years after surgery (6 both legs, 12 one leg). All patients were operated in the same hospital. The inclusion criteria for patients with good functional outcome were: a WOMAC score below 50, a mean health score > 70, a mean knee score [16] > 70 and a functional score [16] > 70, a possible passive knee flexion in the operated knee of 110° or more, and a high subjective satisfaction with the surgery. Twenty age-matched healthy subjects (8 women, 12 men) were recruited from the local community (mainly members of sports clubs) as controls (Table 1). The exclusion criteria for both groups were: previous surgery or pain in the back or lower extremity, rheumatoid arthritis, neurological disease, body mass index (BMI) above 33 kg/m^2, leg length discrepancy > 1 cm, a history of major trauma or a sports injury to the knee and knee surgery within the preceding 6 months or wearing orthopedic insoles.

Patients and control subjects were able to walk without restrictions and ascending stairs without using a handrail. All patients and control subjects provided informed consent prior to participation and the study was approved by the local ethics committee.

Clinical exam

Muscle strength of the knee extensors was clinically estimated according to Daniels and Worthingham [17]. The clinically tested muscle strength of the plantar flexors is estimated via the possible number of heel rises standing on one foot with extended knee. The maximum number of repetitions should be achieved. Lunsford and Perry (1995) recommend a number of 25 repetitions as normal [18]. Range of motion of the lower extremity was measured by the neutral-zero-method. The assessment of the tibia torsion was estimated by the measurement of the transmalleollar axis [19].

Stair climbing and gait analysis

Three-dimensional lower body kinematics and kinetics were measured during level walking and stair ascending using an 8-camera Vicon® motion analysis system (Vicon Mx-System, Oxford Metrics Ltd, Oxford, UK; 200 frames per second) and two AMTI force plates with mounting holes for stairs (OR6-7-2000, Advanced Medical Technology Inc, Watertown, MA, USA; 1000Hz). 22 self-reflecting markers (diameter 14mm) were attached according to the PIG-Model. The lower body was modeled according to Davis et al. and Kadaba et al. [20,21]. Joint kinetics were normalized to body mass. All joint moments are reported as external moments. The upper body was modeled as described by Gutierrez et al. [22]. The angles of the trunk reflect the absolute movement in space. Negative frontal plane trunk angles corresponded to trunk lean to the ipsilateral side and positive angles to trunk lean to the contralateral side. Negative sagittal plane trunk angles corresponded to backward trunk tilt and positive angles to forward trunk tilt.

Subjects practiced stair walking before data collection. The order of walking and stair ascending trials were randomized. The subjects walked at their self-selected speed. Subjects performed each activity while walking on a 10-m level walkway and three stair ascending trials without using the handrail (stair height: 17cm) until data for three trials were collected. In patients with unilateral TKA, the involved leg was assessed, and in patients with bilateral TKA and control subjects, data for the leg with the smaller knee varus/valgus amplitude during gait was used for further analysis. The knee varus/valgus amplitude is a commonly used quality criteria for crosstalk [ESMAC gait courses] because of the known restrictions imposed by the joint anatomy [23].

The stairway (prophysics AG, Kloten, Switzerland; Figure 1) was firmly attached to the platforms and allowed force measurement and moment calculation for each of four consecutive steps. The steps of the stairway are alternately connected to the two platforms so that each force plate measures forces for steps of either the right or the left foot. The dimensions of the stairway were 17 cm x 52 cm x 27 cm. Motion and force data from the second step were used for further analysis. Clinically relevant kinematic parameters were selected according to Perry [24], the parameters describing trunk motion were defined according to Asay et al. [11], and kinetic parameters were defined based on the study of Riener et al. [4].

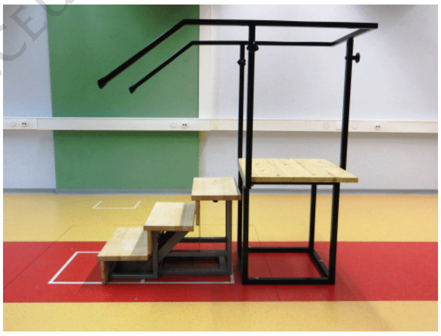

Figure 1: Photograph of the stairway set-up on the force plates. The stairway was attached with threaded inserts on the platforms. The stairway allows for measuring isolated forces and moments generated during each of four consecutive steps.

Parameters and statistical analysis

All statistical analyses were performed in SPSS Version 19.0 (Chicago, IL, USA). Data were checked for normalcy using the Kolmogorov-Smirnov-test. For normally distributed parameters, differences between groups were tested for significance using a Student's t-test. Differences in ordinal parameters (muscle function test) between groups were detected using the Mann-Whitney-U-Test. The level of significance was a priori set to $p<0.05$. In addition, we calculated the 95%-confidence interval of the group differences for all metric and ordinal parameters. Statistical significance was also interpreted on the basis of the 95%-confidence interval of difference [25].

Results

Clinical exam and functional scores

Patients achieved less knee flexion in the clinical exam than the healthy control group (-12.9°, p<0.001) and had more internally rotated hips (+7.2°; p=0.034; Tables 1 and 2). In addition, patients performed 40% fewer heel rises (p=0.059) than the control subjects.

The patients had a mean WOMAC score [26] of 25.12 (± 2.26), a mean health score of 93.35 (± 5.52), a mean knee score [16] of 96.96 (± 2.01) and a functional score of 95.35 (± 5.88).

	Patients (n=18)	Controls (n=20)	Difference 95% CI	P-value t-test
Height [cm]	168 (9)	169 (8)	[-0.1;0.1]	0.852
Weight [kg]	73.4 (10.9)	69.9 (6.4)	[-3.3; 10.2]	0.309
BMI [kg/m^2]	25.8 (2.9)	24.5 (2.6)	[-0.5; 3.1]	0.146
Age [years]	67.8 (8.1)	66.1 (6.4)	[-3.1; 6.5]	0.471

Table 1: Mean (SD) Demographic parameters for the patients with TKA and age-matched control subjects. CI: Confidence Interval. Note: Independent samples t-tests were used to confirm clinically relevant differences indicated by the confidence interval of the difference between groups not containing 0.

	Patients (n=18)	Controls (n=20)	Difference 95% CI	P-value t-test
Knee flexion [°]	121.4 (9.5)	134.3 (10.3)	[6.3;19.0]	<0.001
Knee extension [°]	0.6 (1.6)	0.3 (1.1)	[-1.2; 0.6]	0.499
Hip extension [°]	10.3 (4.4)	7.5 (6.0)	[-0.7; 6.2]	0.113
External hip rotation [°]	28.6 (8.2)	27.0 (11.7)	[-8.3; 5.1]	0.630
Internal hip rotation [°]	35.0 (10.7)	27.8 (9.5)	[-13.9;-0.6]	0.034
Tibia torsion [°]	-23.1 (6.7)	-22.9 (7.2)	[-4.4; 4.8]	0.928
Muscle strength knee extensors	4.9 (0.3)	5.0 (0.2)	[-0.9; 0.2]	0.494
Numbers of heel rises	18.0 (10.1)	29.7 (20.0)	[1.0;22.3]	0.059

Table 2: Mean (standard deviation) clinical parameters for patients after TKA and age-matched control subjects. 95% confidence interval of the difference (CI) and p-value of t-test (metrical parameters) Mann-Whitney-U-Test (ordinal parameters). CI: Confidence Interval. Note: Independent samples t-tests were used to confirm clinically relevant differences indicated by the confidence interval of the difference between groups not containing 0.

Spatio-temporal parameters

Spatio-temporal parameters for level walking did not differ between patients with a well functioning TKA and control subjects. During stair ascending, patients after TKA walked with a slower walking speed (p<0.001), higher cadence (p=0.037) and shorter step length (p=0.004) than the control subjects (Table 3).

	Walking				Stair ascending 17 cm			
	Patients (n=18)	Controls (n=20)	Difference 95% CI	P-value t-test	Patients (n=18)	Controls (n=20)	Difference 95% CI	P-value t-test
Spatio-temporal parameters								
Gait velocity [m/s]	1.05 (0.08)	1.06 (0.06)	[-0.03; 0.02]	0.752	0.44 (0.07)	0.46 (0.07)	[-0.07;-0.02]	<0.001
Cadence [steps/min]	104.2 (8.8)	103.2 (6.5)	[-1.9; 3.9]	0.489	76.1 (10.9)	71.9 (7.2)	[-7.2;-0.2]	0.037
Step length [m]	0.61	0.62	[-0.03; 0.01]	0.215	0.39	0.44	[-0.1; -0.01]	0.004

	(0.05)	(0.04)			(0.05)	(0.06)		
Lower body kinematics								
Foot progression angle initial contact (+ = internal rotation) [°]	-6.2 (5.6)	-8.9 (4.7)	[0.9; 4.7]	0.040	-4.9 (6.3)	-6.8 (5.2)	[-0.1; 4.1]	0.061
Maximum ankle dorsiflexion terminal stance [°]	18.9 (3.1)	15.2 (2.9)	[2.6; 4.8]	<0.001	16.6 (3.9)	15.8 (3.7)	[1.1; 3.9]	<0.001
Minimum knee flexion angle terminal stance & pre swing[°]	9.1 (4.9)	3.1 (3.9)	[4.4; 7.6]	<0.001	11.4 (3.6)	7.5 (4.4)	[2.5; 5.5]	<0.001
Minimum sagittal hip angle terminal stance & pre swing [°]	-8.4 (5.9)	-12.3 (6.5)	[1.6; 6.1]	<0.001	11.3 (6.7)	9.6 (7.2)	[-2.0; -7.1]	<0.001
Mean hip rotation angle mean stance phase [°]	-10.6 (6.7)	-4.2 (7.1)	[-8.9; -3.8]	<0.001	-7.6 (7.4)	-3.6 (7.1)	[-7.8;-2.5]	<0.001
Upper body kinematics								
Anterior trunk tilt [°]	2.2 (3.3)	1.3 (3.8)	[-0.5; 2.2]	0.200	14.9 (5.0)	13.7 (6.6)	[1.4; 5.6]	<0.001
Maximum anterior trunk tilt [°]	2.8 (3.3)	2.1 (3.7)	[-0.7; 1.9]	0.390	17.1 (5.5)	16.5 (6.4)	[1.7; 6.0]	<0.001
ROM trunk tilt stance phase [°]	2.1 (0.8)	2.4 (1.2)	[-0.7; 0.0]	0.070	3.9 (2.3)	4.6 (1.7)	[-3.4; 1.1]	0.291
Initial trunk lean [°]	-0.2 (2.2)	-0.4 (1.9)	[-0.5; 1.0]	0.496	0.6 (2.9)	0.4 (2.6)	[-0.7; 1.3]	0.536
Maximum contralateral trunk lean [°]	2.0 (2.1)	1.7 (1.7)	[-0.4; 1.0]	0.458	3.2 (2.8)	3.8 (3.0)	[-0.9; 1.2]	0.756
Maximum ipsilateral trunk lean [°]	1.6 (2.2)	2.0 (2.2)	[0.4; -1.2]	0.369	2.5 (3.1)	3.5 (2.2)	[0.9; -1.1]	0.890
Initial external trunk rotation [°]	1.9 (2.8)	1.8 (2.1)	[1.0; -0.8]	0.905	6.1 (3.6)	6.6 (3.8)	[1.5; -1.2]	0.818
Maximum internal trunk rotation [°]	3.3 (3.0)	1.9 (2.2)	[0.5; 2.4]	0.005	7.1 (3.6)	7.0 (3.1)	[0.5; 2.9]	0.006
ROM trunk rotation stance phase [°]	6.0 (2.5)	4.7 (2.5)	[0.3; 2.2]	0.008	14.0 (4.1)	14.7 (4.1)	[0.1; 3.1]	0.038

Table 3: Group effects for walking and stair ascending. Mean (SD), 95%-confidence intervals of the difference and p-values of t-test for spatio-temporal and lower and upper kinematic parameters during the stance phase of walking and stair ascending in patients with good functional outcome after TKA and in age-matched control subjects. CI—confidence interval; ROM: Range of Motion. Note: Independent samples t-tests were used to confirm clinically relevant differences indicated by the confidence interval of the difference between groups not containing 0.

Lower body kinematics

For stair ascending and level walking, patients after TKA had greater ankle dorsiflexion (stair ascending +0.8°, $p<0.001$; level walking, +3.7°, $p<0.001$), greater knee flexion during terminal stance (stair ascending +3.9°, $p<0.001$; level walking +6.0°, $p<0.001$), lower hip extension during terminal stance (stair ascending -1.7°, $p<0.001$; level walking -3.9°, $p<0.001$) and more externally rotated hips throughout the stance phase (stair ascending +4.0°; p<0.001; level walking +6.4°, p<0.001) than control subjects (Table 3). At initial contact patients` feet showed higher external rotation (+2.7°, p=0.400) than control subjects for level walking. This was not the case for stair ascending (p=0.061).

Upper body kinematics

Patients after TKA walked with a more internally rotated trunk (stair ascending +0.1°, p=0.006; level walking +1.4°, p=0.005) and a greater trunk rotation range of motion (stair ascending +0.7°, p=0.038; level walking+1.3°, p=0.008) during stance than the control group for both stair ascending respectively level walking. Patients had a more anteriorly tilted (0.8°, p=0.001) and maximum (0.6°, p=0.001) trunk position at initial contact than control subjects for stair ascending but not for level walking (Figures 2 and 3).

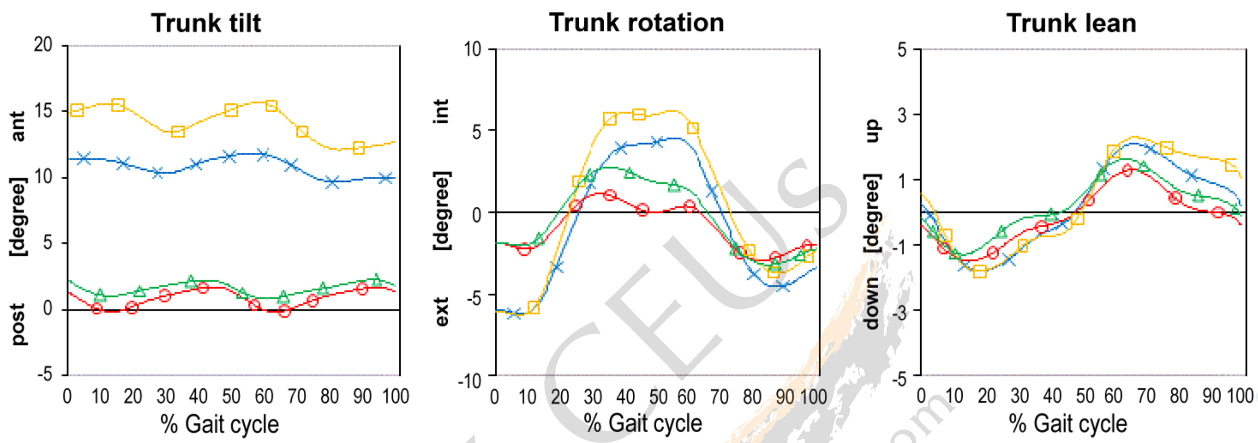

Figure 2: Mean trunk angles in patients after total knee arthroplasty with good outcome (TKA, n=18) and age-matched healthy subjects (n=20) during level walking and stair ascending. Yellow rectangle: patients stair ascending; green triangle: patients level walking; blue cross: controls stair ascending; red circle: controls level walking.

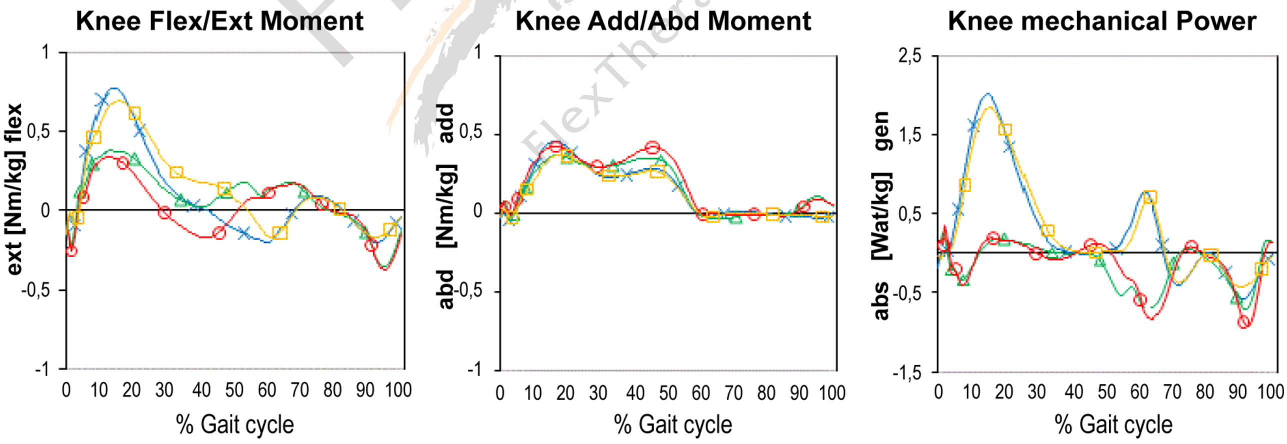

Figure 3: Mean knee moments sagittal plane, mean knee moments frontal plane and mean knee power in patients after total knee arthroplasty with good outcome (TKA, n=18) and age-matched healthy subjects (n=20) during level walking and stair ascending. Yellow rectangle: patients stair ascending; green triangle: patients level walking; blue cross: controls stair ascending; red circle: controls level walking

Lower body kinetics

For stair ascending and level walking, patients had larger maximum knee flexion moments during terminal stance & pre swing (stair ascending +27%, p=0.067; level walking +19, p=0.024), smaller first peak knee adduction moments (stair ascending -17%, p=0.020; level walking –9%, p=0.042), smaller maximum ankle dorsiflexion moments in terminal stance (stair ascending -11%, p<0.001; level walking -5%, p=0.021), smaller maximum hip extension moments during terminal stance & pre-swing (stair ascending -19%, p=0.003; level walking -11%, p=0.007) and greater knee extension moments during terminal stance & pre-swing (stair ascending -17%, p<0.001; level walking 90%, p<0.001) than control subjects.

Patients had a smaller ankle power absorption for stair ascending (-45%, p<0.001) and a greater ankle power absorption during level walking (+20%, p<0.001) than control subjects. The knee flexion moment in loading response was 9% lower (p=0.067) for the patients during stair ascending and respectively 18% higher (p=0.024) during level walking. In addition, for level walking patients had smaller knee flexion impulses (-14%, p=0.016), a smaller maximum knee power (-22%, p=0.003), smaller 2nd peak knee adduction moments (-14%, p=0.015), 2nd peak hip adduction moments (-12%, p<0.001) and greater maximum hip flexion moments (+18%, p=0.008) than control subjects. These parameters did not differ between patients and control subjects for stair ascending. For further information see table 4 (Table 4).

Discussion

The purpose of this study was to provide full body kinematics and kinetics for level and stair walking in patients with good physical function after TKA and to test the hypothesis that differences in whole body mechanics between patients with TKA and age-matched control subjects become more evident during stair ascending than during level walking. The hypothesis could only be confirmed for the trunk mechanics where 22% of the analyzed parameter showed differences during level walking (44% during stair ascending) when comparing the TKA-patients and the age-matched controls. Although the patients walked with a slower velocity during stair ascending and the same velocity during level walking the results show more often differences in joint kinetics and lower body angles for level walking than for stair ascending. Of the analyzed kinetic parameters 86% show differences during level walking while during stair ascending only 50% of the parameters differed between groups. In lower body kinematics 100% of the analyzed parameters were different between the groups during level walking, while during stair ascending 80% of the analyzed parameters were different [27].

Our lower body kinetic results confirm those of previous studies [28], that even in patients with good physical function after TKA sagittal plane knee moment patterns differ from those of age-matched healthy persons. Although patients did show a typical biphasic flexion-extension moment pattern, their knee flexion and extension moments for both activities differed from values in the control group. Higher knee flexion moments and lower knee extension moments have been proposed as a compensatory stabilizing mechanism [27] for abnormal function of the quadriceps muscle because of loss of function or loss of muscle force after extended periods of pain.

The absolute demand on the quadriceps muscle is higher for stair ascending than for level walking. The knee flexion moment of the controls during loading response was 57% higher for stair ascending than for level walking; for the TKA-patients it was 40% higher for stair ascending. Nevertheless there are no differences in knee flexion-extension impulse (p=0.384) or maximal knee power (p=0.094) during stance between patients and control subjects during stair ascending. In addition, we did not find differences in quadriceps muscle function in the clinical exam (p=0.494) between patients and control subjects. Initially these results suggest that at least in patients with good functional outcome after TKA the quadriceps muscle remains sufficiently strong after TKA. McClelland et al. [28] reported that patients had higher knee moments at faster walking speeds where the mechanical demands are higher and concluded that quadriceps strength is not a limiting factor for sufficiently balancing external knee flexion moments during ambulation.

	Walking				Stair ascending 17 cm			
	Patients (n=18)	Controls (n=20)	Difference 95% CI	P-value t-test	Patients (n=18)	Controls (n=20)	Difference 95% CI	P-value t-test
Maximum ankle dorsiflexion moment terminal stance [Nm/kg]	1.38 (0.14)	1.45 (0.16)	[-0.12; 0.01]	0.021	1.20 (0.15)	1.34 (0.18)	[-0.19;-0.07]	<0.001
Maximum ankle power absorption [Watt/kg]	0.60 (0.14)	0.50 (0.16)	[0.04; 0.16]	<0.001	0.22 (0.13)	0.40 (0.36)	[-0.32;-0.12]	<0.001
Maximum ankle power generation [Watt/kg]	3.12 (0.56)	3.05 (0.6)	[-0.15; 0.29]	0.510	2.89 (0.53)	3.65 (0.69)	[-0.43; 0.03]	0.090
Maximum knee flexion moment loading response [Nm/kg]	0.45 (0.17)	0.38 (0.18)	[-0.16;-0.05]	0.024	0.75 (0.21)	0.88 (0.22)	[-0.15;-0.01]	0.067
Maximum knee extension moment terminal stance & pre swing [Nm/kg]	-0.02 (0.15)	-0.20 (0.13)	[0.06; 0.27]	<0.001	-0.24 (0.08)	-0.29 (0.10)	[0.05; 0.19]	<0.001
Maximum knee flexion moment terminal stance & pre swing [Nm/kg]	0.25 (0.09)	0.21 (0.05)	[0.00; 0.06]	0.024	0.28 (0.15)	0.22 (0.20)	[0.06; 0.19]	<0.001
Knee flexion impulse [Nm*s/kg]	23.73 (9.55)	27.52 (6.55)	[-6.85;-0.73]	0.016	29.15 (13.97)	28.59 (7.69)	[-2.40; 6.11]	0.384

1st peak knee adduction moment [Nm/kg]	0.41 (0.14)	0.45 (0.09)	[-0.09; 0.00]	0.042	0.42 (0.20)	0.53 (0.13)	[-0.14;-0.01]	0.020
2nd peak knee adduction moment [Nm/kg]	0.38 (0.15)	0.44 (0.10)	[-1.08; 0.01]	0.015	0.32 (0.15)	0.31 (0.11)	[-0.05; 0.05]	0.939
Maximum knee power maximum [Watt/kg]	0.42 (0.15)	0.54 (0.24)	[-0.18; 0.04]	0.003	1.99 (0.54)	2.30 (0.58)	[-0.38; 0.03]	0.094
Maximum hip flexion moment loading response [Nm/kg]	0.78 (0.28)	0.66 (0.19)	[0.03; 0.20]	0.008	0.67 (0.22)	0.78 (0.20)	[-0.09; 0.07]	0.790
Maximum hip extension moment terminal stance & initial swing [Nm/kg]	0.92 (0.21)	0.83 (0.16)	[0.03; 0.16]	0.007	0.43 (0.20)	0.36 (0.16)	[0.01; 0.14]	0.003
1st peak hip adduction moment [Nm/kg]	0.88 (0.14)	0.90 (0.12)	[-0.07; 0.03]	0.352	0.81 (0.15)	0.80 (0.14)	[-0.04; 0.06]	0.711
2nd peak hip adduction moment [Nm/kg]	0.73 (0.15)	0.83 (0.10)	[-0.15;-0.05]	<0.001	0.69 (0.18)	0.69 (0.12)	[-0.07; 0.04]	0.675

Table 4: Group effects for walking and stair ascending. Mean (SD), 95%-confidence intervals of the difference and p-values of t-test for kinetic parameters during the stance phase of walking and stair ascending in patients with good functional outcome after TKA and in age-matched control subjects. CI: Confidence Interval. Note: Independent samples t-tests were used to confirm clinically relevant differences indicated by the confidence interval of the difference between groups not containing 0.

In contrast, theoretical considerations have shown that strong knee extensors could actively support the plantar flexion-knee extension couple [29]. Our results showed that patients remained in a more flexed knee position during terminal stance and pre swing (stair ascending +6.0°, $p<0.001$; level walking +3.9°, $p<0.001$) and produced less knee extension moment during terminal stance and preswing (both motion $p<0.001$) than age-matched control subjects. Therefore it seems that quadriceps strength is not strong enough to support the plantar flexion-knee extension couple.

In addition, lower ankle dorsiflexion moments in patients for both conditions (stair ascending $p<0.001$, level walking $p=0.021$) and poorer performance in the muscle function test of the plantar flexors ($p=0.059$) compared to healthy subjects suggest weakness of the plantar flexors, although there were no differences in the ankle muscle power (stair ascending $p=0.090$; level walking $p=0.510$). During walking, one function of the plantar flexors is to extend the knee passively via the plantar flexion-knee extension couple [30]. Hence, plantar flexor weakness would result in reduced knee flexion-extension impulse ($p=0.016$) and lower maximal knee power ($p=0.003$) and knee extension moment in terminal stance and preswing ($p<0.001$) as observed in our study for level walking in patients after TKA. Moreover, our patients ascended stairs with a slightly more anterior trunk tilt which may be yet another indication of muscle weakness of the leg muscles after TKA. The trunk of TKA patients was bent more forward during stair ascending, presumably intentionally to improve the knee moments. This small difference in trunk position during stair ascending did not result in a better knee-extension moment during terminal stance and pre swing in patients when ascending stairs ($p<0.001$). But it is possible, that even if you have to draw a possible measurement error into consideration, that the higher trunk tilt have contributed to controlling and reducing the large knee flexion moment during the loading phase during stair ascending (0.75Nm/kg) to remain below normal levels (0.88Nm/kg). Our results show that the TKA-patients with the more forward bent upper body show a 15% lower knee flexion moment in the loading response than the controls during stair ascending. Trunk leaning as a gait adaption is in accordance with the results of patients with knee osteoarthritis during stair walking [11] and TKA-patients during level walking [31]. In addition to a more anterior bent trunk we also identified a slower walking velocity for our patients during stair ascending. Bjerke et al. (2014) also found a slower walking velocity as a compensation mechanism. However they did not find a forward bent trunk for their TKA-patients during stair ascending [12].

The results indicate that TKA-patients (although they have no problems at the moment) should strengthen their knee extensors and –what is often less considered- their calf muscles to improve knee kinetics in the sagittal plane for level walking and ascending stairs. This is important because the loosening of the prosthesis has been attributed to excessive knee flexion moments [32,33].

Besides muscle weakness it is possible that patients in our study adopted different compensation mechanisms before surgery and that these mechanisms still remain after TKA (e.g. more flexed knee position). A limitation of the study is that no measurement was carried out before the surgery in the TKA-group. Therefore, the effect of TKA could not be evaluated. Another limitation is that we analyzed TKA-patients with either one operated leg or a prosthesis in both legs together. Because no asymmetries were detected in the individual gait analysis of the patients we accepted this limitation. However, we analyzed whether well functioning TKA-patients would return to a normal gait pattern or still have gait deviations in comparison to healthy age-matched controls.

In contrast to a study from Mündermann et al. (2005) with gonarthrosis-patients we found a higher hip extension moment (stair ascending $p=0.003$, level walking $p=0.007$) of the TKA- patients in terminal stance/initial swing during level and stair walking [34]. It seems possible that the higher requirements for the hip flexors are caused by a redistribution of joint tasks from the knee to the hip [35]. The foot progression angle of the TKA-patients was more externally rotated during gait (p=0.040), to reduce the knee adduction moment [10,36,37]. We could not find a more rotated foot progression angle during stair ascending (p=0.061). We observed more external hip rotation during stair ascending (-4.0°, p<0.001) and level walking (-6.4°, p<0.001) in our patient group. In the passive range of motion test the TKA-patients show no differences in external hip rotation (p=0.630), but they show higher values of internal hip rotation (+7.2°, p=0.034) than the control group. Recent studies with adolescents with a higher externally rotated tibia and both with an more externally rotated tibia and a higher antetorsion [38] and of an isolated higher antetorsion [39] showed a higher internal hip rotation during gait and deviations of the foot progression angle in dependence of the malalignment. Since the foot progression angle is slightly more internally rotated in our patients group (during gait), maybe the hip of the TKA-patients was turned outwards on purpose to reduce the knee adduction moment before surgery and now this gait pattern is still present.

Conclusion

In summary, it seems that stair ascending does not give clinically relevant additional information in comparison to the isolated gait analysis for our analyzed groups, although the sagittal knee joint kinetics show much higher requirements during stair ascending.

The study shows that considering adjacent joints gives more additional information for treatment recommendation than the additional analysis of the trunk when comparing patients after TKA to healthy seniors.

The data of the controls, as well as of patients after TKA, could serve as a base line for further gait analysis including upper body movement for patients with clinical problems after total knee replacements. Training studies with a focus on a group with gait retraining and a focus on a group with plantar flexor strengthening might help a better distinction between gait adaption and weakness.