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Is ACL deficiency always a contraindication for medial UKA? Kinematic and kinetic analysis of implanted and contralateral knees

Lorena Suter[a,1], Adrian Roth[a,1], Michael Angst[a], Fabian von Knoch[b], Stefan Preiss[c], Renate List[a,c], Stephen Ferguson[a], Thomas Zumbrunn[a,*]

[a] Institute for Biomechanics, ETH Zürich, Switzerland
[b] Zurich Bone and Joint Institute, Switzerland
[c] Schulthess Klinik Zürich, Switzerland

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ABSTRACT

Background: Prevalence of knee osteoarthritis increases because life expectancy continues to rise with an active patient population. Hence, the concept of unicompartmental knee arthroplasty (UKA) has regained popularity as a treatment option for unicompartmental knee osteoarthritis. Anterior cruciate ligament (ACL) deficiency is widely considered as a contraindication for UKA, however, there are conflicting reports. If otherwise indicated, some surgeons consider UKA for ACL-deficient patients using a modified surgical technique, with a reduction of posterior tibial slope.

Research question: The purpose of this study was to evaluate outcomes in UKA patients with ACL deficiency in comparison to a conventional UKA group (intact ACL) by the measurement of knee kinematics and kinetics.
Methods: Ten patients with conventional UKA and an intact ACL and eight patients with an ACL-deficient UKA and a reduced posterior tibial slope relative to the native knee were recruited. Three-dimensional joint kinematics of the knee were measured, using skin markers and an infrared optical motion capture system. Ground reaction forces (GRF) were measured with force plates in all three directions. Level walking, ramp descent and stair descent were analyzed, comparing implanted and contralateral native knees and the two UKA groups.
Results: No significant differences in kinetics and kinematics were observed between conventional UKA and ACL-deficient UKA groups for any of the activities. However, some asymmetries in GRF between the implanted and contralateral side were present for the ACL-deficient group, during level walking (unloading rate) and stair descent (stance time).
Significance: Promising outcomes of the ACL-deficient UKA group suggest that ACL deficiency may not always be a contraindication. Therefore, ACL-deficient UKA could be an alternative treatment option to total knee arthroplasty for an appropriate surgeon selected patient population.

1. Introduction

In the United States alone, around 4.7 million individuals live with a total knee arthroplasty (TKA) [1] and more than 600'000 knee implantations are performed yearly [2]. These numbers are increasing with the aging population [1] and a growing desire for improved mobility and quality of life. The main indication for knee arthroplasty is advanced osteoarthritis (OA), with approximately 13% of women and 10% of men older than 60 years suffering from symptomatic knee OA [3]. With isolated OA in the medial or lateral compartment of the knee joint, unicompartmental knee arthroplasty (UKA) is a common treatment option [4], mostly performed in the medial tibiofemoral compartment [5]. UKA has gained popularity with its smaller surgical procedure and intact lateral (or medial) compartment, including soft-tissue preservation. Functional advantages of UKA, compared to TKA, are greater postoperative range of motion (ROM) and preservation of normal kinematic function [4,6,7]. Nonetheless, fewer than 10% of all primary knee replacements are UKAs [4,8], even though up to half of all patients are potential UKA candidates [4].

In the native knee, the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) play a major role in knee kinematics and joint stability [9]. In neutral tibial rotation, the ACL is the primary

* Corresponding author at: Institute for Biomechanics, ETH Zürich Hönggerbergring 64, HPP O14, 8093 Zürich, Switzerland.
E-mail address: tz@hest.ethz.ch (T. Zumbrunn).
[1] Equal contribution.

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restraint for anterior drawer and the PCL for posterior drawer [9]. In extension, the ACL is under tension and responsible for the so-called "screw-home" mechanism, while the PCL is not under tension [10]. In mid-flexion both ACL and PCL, provide knee joint stability and at high flexion, the PCL is responsible for posterior femoral rollback [11–13]. Additionally, other passive restraints are present, nevertheless, the main stabilizing and restraint mechanism in anteroposterior (AP) tibial translation is provided by the ACL [14,15].

Some studies stated that ACL deficiency is a relative contra-indication for UKA implantation, leading to high failure rates [16,17], whereas others showed no increase in revision rates compared to conventional UKA [18,19]. It has been shown that the ACL is intact in around 61%–78% of OA knees [20,21], resulting in a substantial proportion of ACL-deficient knees undergoing TKA. The ACL forces after UKA are comparable to those in native knees, indicating a similar role of the ACL in knees following UKA [22]. Suggs et al. demonstrated in cadaveric knees that AP stability of the knee after UKA with an intact ACL was similar to that of the native knee, while UKA with a deficient ACL showed more than twice the knee movement under anterior tibial loading [22]. On the other hand, Boissonneault et al. proposed that a functionally intact ACL is not always an essential prerequisite for a successful UKA [19]. To improve stability in the ACL-deficient knee, the posterior tibial slope can be reduced [23]. With an increased tibial slope the resting position of the femur shifts posteriorly and the posterior femoral rollback in normal and ACL-deficient knees increases along with tibial shear forces [23–26]. A decreased tibial slope in ACL-deficient UKA results in similar femoral rollback compared to healthy knees [27] and a more stable knee in flexion [18].

The aim of this study was to investigate the kinematics and kinetics in conventional medial UKA patients with an intact ACL, and medial UKA patients with a deficient ACL, during various daily activities. Additionally, we analyzed the contralateral native knee for symmetry comparison.

2. Methods

For this study, ten patients (8 male, 2 female; 67 years ± 10 years; BMI 25.3 ± 2.7; postop 21 months ± 5 months) were recruited with a contemporary, fixed bearing medial UKA (SIGMA High Performance Partial Knee System), implanted following standard surgical technique, and with an intact ACL. Additionally, eight patients (3 male, 5 female; 63 years ± 7 years; BMI 26.9 ± 2.2; postop 76 months ± 16 months) were recruited with a deficient ACL and following an altered surgical technique. Patients were recruited at least one year postoperatively from two different centers. Preoperative assessment of ACL deficiency was identified clinically by means of Lachman test, through imaging including lateral knee radiographs and magnetic resonance imaging (MRI), as well as intraoperative assessment. With an intact ACL, the tibial component of the UKA was implanted matching the native tibial slope, or slightly reduced for knees with a posterior slope of more than 7°, resulting in an average reduction of 23% for this patient group. With a deficient ACL, the posterior tibial slope was reduced by 39% on average compared to the native tibial slope. A detailed description of inclusion and exclusion criteria is given in Table 1. All patients provided their written informed consent prior to data collection, and the institutional review board and the Zurich cantonal ethics committee (BASEC-No. 2016-00438) approved this study.

Kinetics and kinematics of level walking, ramp descent and stair descent were evaluated at self-selected velocity by means of skin marker and ground reaction force measurements. All motion tasks were performed with a moving fluoroscope tracking the patient's knee [28], used for other aspects of this study. The instrumented stairs had a standard inclination of 31.8° with a run of 29 cm and a rise of 18 cm, while the instrumented ramp consisted of a downward slope of 10° [28]. Each patient performed five valid gait cycles for all analyzed motion tasks.

2.1. Kinematics

The 3D motion analysis system comprised 22 infrared-cameras (Vicon MX system, Oxfords Metrics Group, UK) with a capture frequency of 100 Hz. The Institute for Biomechanics (IfB) lower body Marker-Set of 55 skin markers was used [29]. The segmental position and orientation was determined based on a least squares fit of marker point clouds [30]. The clinical description of Grood and Suntay was used for intersegmental joint rotations [31]. Four basic motion tasks [29] were performed to functionally determine ankle, knee and hip joint centers or axes, respectively. Thus, the influence of anatomical landmark misplacement was decreased and higher joint center accuracy was obtained [32]. The ankle and hip joints were modelled as ball-and-socket joints and the knee as a hinge joint. Furthermore, all kinematic data were normalized over a gait cycle. Flexion/extension, internal/external (IE) rotation and varus/valgus (VV) rotation were analyzed.

2.2. Kinetics

Five integrated, and two mobile force plates (Kistler Instrumentation, Winterthur, Switzerland) were used in a setup, mechanically decoupled from the surroundings to limit noise of force measurements [33]. Ground reaction force (GRF) was recorded in the vertical, anteroposterior (AP) and mediolateral (ML) direction, with a frequency of 2 kHz over the stance phase of gait cycles, and normalized to body weight (BW). Further, maximum joint moments were calculated in the sagittal and frontal plane based on the kinetic force plate measurements and the associated kinematics [34].

2.3. Symmetry index

For the kinetic comparison of the ipsilateral and contralateral leg the symmetry index (SI) [35] was used, which was calculated as: $SI = \frac{2*(x_{ipsi} - x_{cont})}{(x_{ipsi} + x_{cont})} * 100$; x_{ipsi} = value of variable for ipsilateral side, x_{cont} = value of variable for contralateral side. Asymmetry was defined as a mean SI below or above an arbitrary cut-off value of ± 10% [35]. Additionally, the SI needed to be outside the 95% confidence Interval to be considered asymmetric. The confidence interval was calculated as $t_{df;(0.05)}$*Standard Deviation(SD) [36].

2.4. Statistical analysis

An open-source one-dimensional Statistical Parametric Mapping (SPM) code (v0.4, www.spm1d.org), was used for statistical analysis, evaluating the entire waveform of gait cycles [37,38]. SPM integrated paired two-tailed t-tests were applied for analysis of the ipsilateral and contralateral leg within the same subject. SPM with unpaired two-tailed t-tests were used for the comparison of the two UKA groups. Additionally, a Bonferroni correction was applied for post hoc multiple comparisons, considering the analysis of three activities (significance level adjusted from 0.05 to 0.02). To check the repeatability of gait cycles within activities of each patient, the coefficient of multiple correlation was calculated for the ipsilateral and contralateral side over all trials [39]. All calculations were performed in Matlab (Mathworks, Inc., Natick, USA).

3. Results

3.1. Level walking

Knee flexion, IE rotation and VV rotation during level walking over the whole gait cycle were recorded for the conventional UKA patients (Fig. 1) and for ACL-deficient UKA patients (Fig. 2). All kinematic and kinetic waveforms were similar throughout the gait cycle without any significant differences between conventional and ACL-deficient UKA

Table 1
Inclusion and Exclusion Criteria.

	Inclusion Criteria	Exclusion Criteria
Universal	• *Medial SIGMA High Performance Partial Knee System due to medial OA* • *BMI ≤ 32* • *good functional outcome, KOOS > 70* • *no or very low pain, VAS < 2* • *Follow-up at least one year postop* • *Standardized general health survey score (SF-12) within the normal range for people in their age group*	• *Actual significant problem on lower extremities* • *Misaligned UKA* • *Severe joint instability* • *Any other arthroplasty at the lower extremities* • *Patient incapable to understand and sign informed consent* • *Incapable of performing the motion tasks* • *Pregnancy*
Conventional UKA	• *Intact/ functional ACL*	• *Deficient/ suboptimal ACL (Lachman Test)*
ACL-deficient UKA	• *Deficient/ suboptimal ACL* • *Central to posterior wear of medial tibial plateau (preop MRI)* • *Reduced tibial posterior slope after UKA (post-op radiograph)*	• *Intact/ functional ACL*

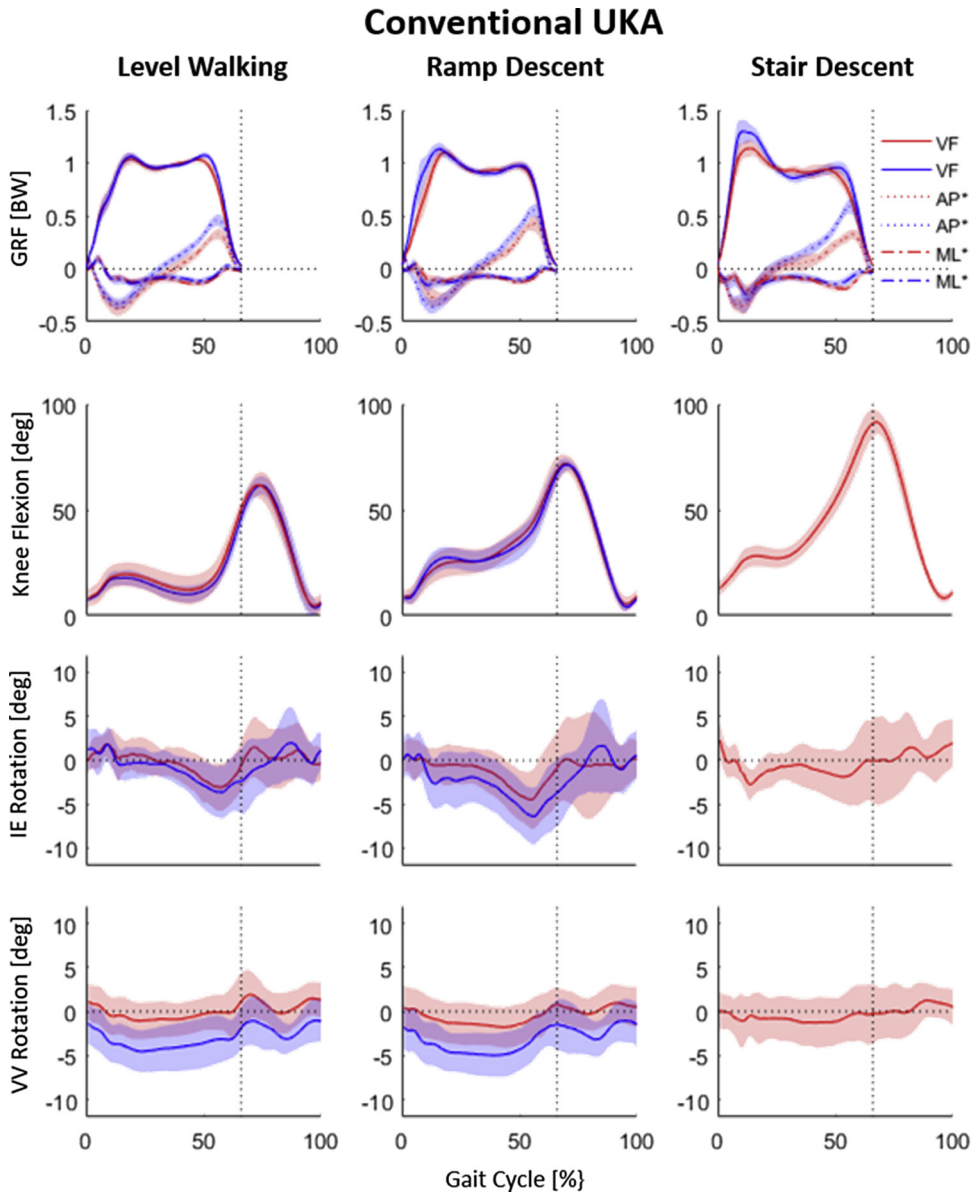

Fig. 1. Ipsilateral (red) and contralateral (blue) graphs of conventional UKA patients. First column: Level walking, second column: Ramp descent, third column: Stair descent. First row: Average GRF normalized to BW (VF: vertical force, AP: + anterior, ML: + medial, * visualized threefold). Second row: Knee Flexion, third row: IE Rotation (+ femur internal), fourth row: VV Rotation (+ varus) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

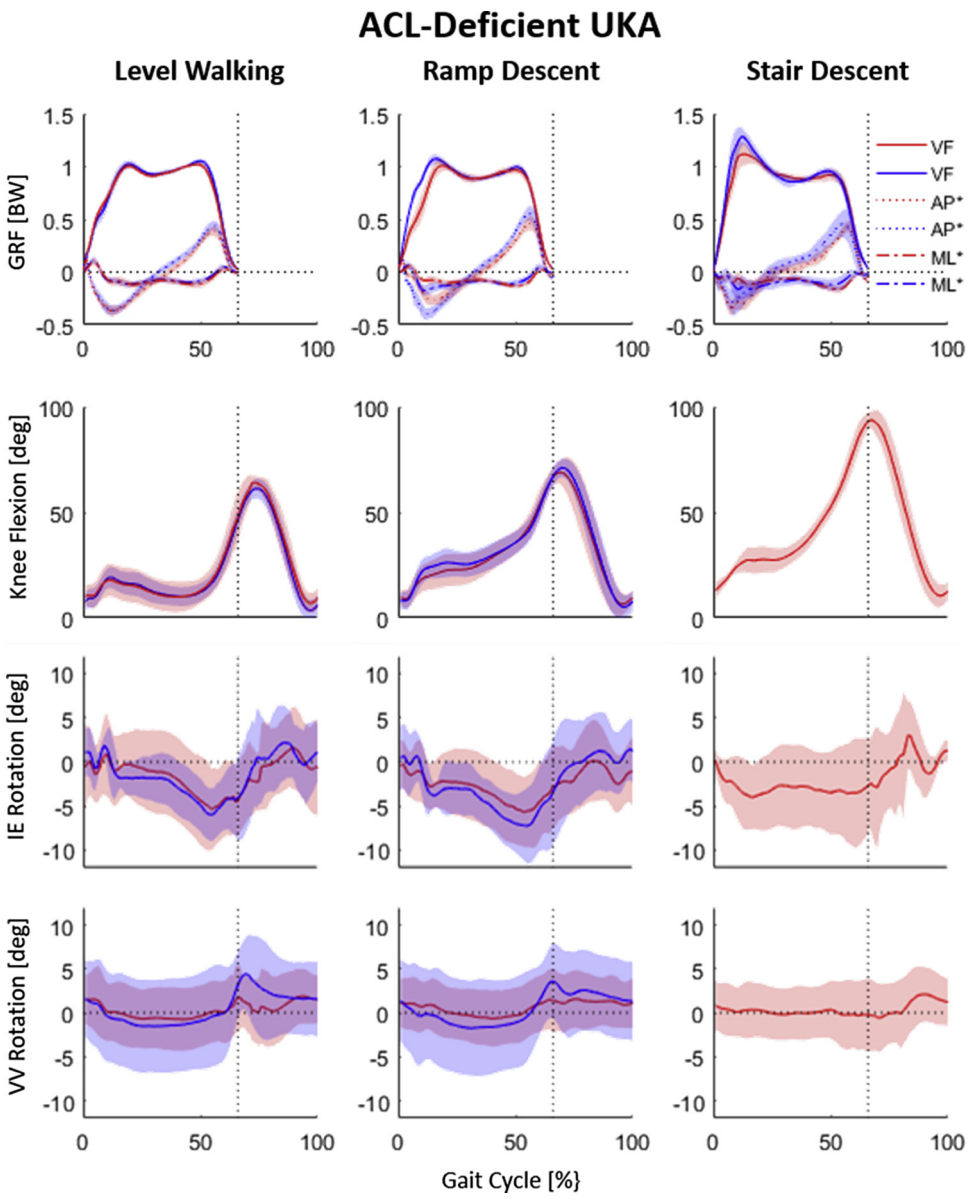

Fig. 2. Ipsilateral (red) and contralateral (blue) graphs of ACL-deficient UKA patients. First column: Level walking, second column: Ramp descent, third column: Stair descent. First row: Average GRF normalized to BW (VF: vertical force, AP: + anterior, ML: + medial, * visualized threefold). Second row: Knee Flexion, third row: IE Rotation (+ femur internal), fourth row: VV Rotation (+ varus) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

patients (Fig. 3). For comparison within patients (ipsilateral vs. contralateral), none of the kinematic waveforms showed any differences (Figs. 1 and 2), and kinetic asymmetry was only found for the unloading rate in the ACL-deficient UKA group (Tables 2 and 3). In the conventional and ACL-deficient UKA groups, level walking was performed with an average gait velocity of 0.87 ± 0.05 m/s and 0.85 ± 0.12 m/s respectively.

3.2. Ramp descent

The three-dimensional joint kinematics of ramp descent were similar over the whole gait cycle for both UKA groups. No significant differences were found between the groups for kinematic, kinetic waveforms (Fig. 3). Within patients, there was no significant difference between ipsilateral and contralateral waveforms in both patient groups (Figs. 1 and 2) and none of the symmetry parameters for the kinetic analysis showed any differences (Table 2 and 3).

3.3. Stair descent

During stair descent, the experimental set up limited investigation of kinematics to the implanted leg, only allowing comparison between the two UKA groups. No significant differences were found in kinematics and kinetics throughout the whole gait cycle between the two groups (Fig. 3). Asymmetries in GRF were only present for stance time of ACL-deficient patients (Tables 2 and 3).

There was no difference in sagittal nor frontal knee joint moments between the two UKA groups for the implanted and contralateral leg during any activity. For the comparison between the ipsi and contralateral leg, there was no significant difference for the sagittal moment in all activities except for ramp descent in the intact ACL group. In the UKA group with an intact ACL, a significant reduction was found in frontal joint moments for the implanted leg during level walking and stair descent, and in the ACL-deficient group for level walking (Table 2).

The coefficient of multiple comparison (CMC) across all parameters

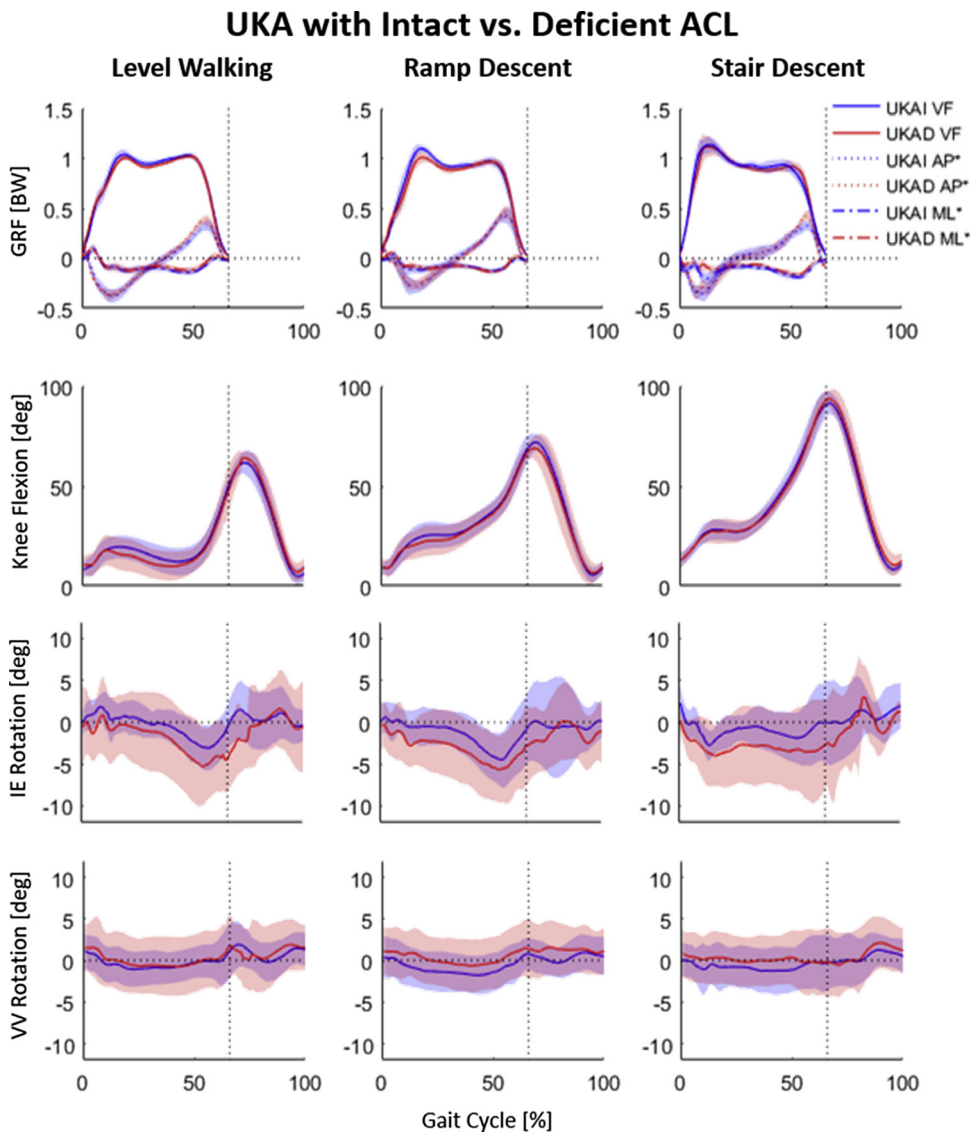

Fig. 3. Comparison of conventional UKA (red) and ACL-deficient UKA patients (blue). First column: Level walking, second column: Ramp descent, third column: Stair descent. First row: Average GRF normalized to BW (VF: vertical force, AP: + anterior, ML: + medial, * visualized threefold). Second row: Knee Flexion, third row: IE Rotation (+ femur internal), fourth row: VV Rotation (+ varus) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

revealed good trial repeatability within patients for a given activity. In the conventional UKA group, the range of CMC was 85%–99% for kinematics, and 76%–99% for kinetics. In the ACL-deficient group, the range of CMC was 64%–100% (with an outlier of one parameter showing 27%) for kinematics and 73%–99% for kinetics.

4. Discussion

There were no significant differences in kinematics and in kinetics between the two UKA groups across all three motion tasks. For all activities, flexion, internal/external (IE) rotation and varus/valgus (VV) rotation show similarities between ipsilateral and contralateral legs as well as between the two groups. However, it appears that the standard deviation is larger for IE and VV rotation, in contrast to flexion and kinetic parameters. This may be linked to skin marker artefacts, less prevalent for the large range of flexion, in contrast to other rotations in the knee joint (e.g. rotation around long axis of limbs). It could also have some effect on the accuracy of joint moments, particularly the frontal plane (abduction/adduction) due to the small lever arms. This was also confirmed by the literature, showing substantial differences in calculated frontal plane knee moments using motion capture [40–42]. However, the higher frontal plane knee moments in the contralateral leg compared to the ipsilateral leg in our study are worth noting, as there might be a compensation mechanism, avoiding high moments in the implanted knees.

Collectively, these data represent a common knee joint kinematics pattern in agreement with previous reports on human level walking and human sloped walking [43,44]. The GRF patterns during level walking were comparable to healthy [45,46], however, of lesser magnitude due to the reduced walking velocity, which also resulted in a less pronounced “double peak” shape. In both groups, the decelerating (braking) impulse in the walking direction at the beginning of stance phase was higher and over a longer portion of stance phase for the ipsilateral leg, in contrast to the contralateral leg. Generally, the accelerating and decelerating impulse in the walking direction are reported of equal magnitude during normal gait, at constant velocity and similar loading of the legs [45,47]. This indicates a different loading behavior of the implanted legs for both UKA groups. With higher velocities in the control setting, the loading was more balanced, indicating that the difference partially resulted from the lower velocities

Table 2
Kinetic parameters of conventional (UKAI) and ACL-deficient (UKAD) UKA groups for UKA implanted (ipsi) and contralateral (cont) side. Reported are stance time (T), first peak (Max_1), second peak (Max_2), local minimum (Min), loading rate(L_r), unloading rate (U_r), ratio of accelerating and decelerating impulse in walking direction (Acc/Dec), Maximum AP Force (AP_{Max}) and Minimum AP Force (AP_{Min}). Loading rate and unloading rate were defined as a straight line through 80% of first peak or second peak respectively, according to Stüssi and Debrunner [39]. Additionally, peak knee joint moments in sagittal (M_{Sag}) and frontal plane (M_{Front}) were calculated relative to bodyweight (BW), * significant difference between ipsi and contralateral leg ($p < 0.02$).

Motion Task	Group	Side	T [s]	Max_1 [BW]	Max_2 [BW]	Min [BW]	L_r [BW/s]	U_r [BW/s]	Acc /Dec	AP_{Max} [BW]	AP_{Min} [BW]	M_{Sag} [Nm/BW]	M_{Front} [Nm/BW]
Level Walking	UKAI	Ipsi	0.91 ± 0.09	1.07 ± 0.06	1.04 ± 0.06	0.91 ± 0.05	5.22 ± 0.97	−5.78 ± 0.79	0.65 ± 0.18	0.11 ± 0.02	−0.14 ± 0.02	0.36 ± 0.18	0.60 ± 0.19*
		Cont	0.91 ± 0.09	1.11 ± 0.08	1.09 ± 0.07	0.91 ± 0.05	5.14 ± 1.3	−6.28 ± 1.04	1.42 ± 0.32	0.16 ± 0.02	−0.13 ± 0.02	0.31 ± 0.18	0.74 ± 0.19*
	UKAD	Ipsi	0.91 ± 0.11	1.03 ± 0.03	1.03 ± 0.03	0.90 ± 0.03	4.90 ± 1.11	−5.45 ± 0.88	0.73 ± 0.22	0.13 ± 0.02	−0.14 ± 0.02	0.36 ± 0.25	0.58 ± 0.17*
		Cont	0.92 ± 0.11	1.07 ± 0.04	1.06 ± 0.03	0.91 ± 0.05	4.77 ± 1.44	−6.13 ± 0.95	1.19 ± 0.23	0.15 ± 0.02	−0.13 ± 0.03	0.35 ± 0.17	0.73 ± 0.23*
Ramp Descent	UKAI	Ipsi	0.92 ± 0.10	1.13 ± 0.13	0.99 ± 0.08	0.87 ± 0.06	5.36 ± 1.66	−5.88 ± 0.76	1.43 ± 0.28	0.16 ± 0.02	−0.11 ± 0.03	0.88 ± 0.24*	0.55 ± 0.16
		Cont	0.89 ± 0.08	1.21 ± 0.14	1.01 ± 0.08	0.85 ± 0.06	7.82 ± 2.29	−6.12 ± 1.30	1.52 ± 0.11	0.19 ± 0.02	−0.14 ± 0.04	1.03 ± 0.29*	0.70 ± 0.13
	UKAD	Ipsi	0.91 ± 0.10	1.07 ± 0.05	0.98 ± 0.05	0.85 ± 0.03	4.86 ± 0.78	−5.84 ± 1.20	1.69 ± 1.03	0.16 ± 0.02	−0.11 ± 0.03	0.76 ± 0.27	0.47 ± 0.06
		Cont	0.87 ± 0.08	1.13 ± 0.09	1.01 ± 0.05	0.85 ± 0.04	7.52 ± 1.85	−6.49 ± 0.93	1.31 ± 0.25	0.20 ± 0.03	−0.15 ± 0.05	0.91 ± 0.25	0.60 ± 0.19
Stair Descent	UKAI	Ipsi	0.98 ± 0.13	1.29 ± 0.16	0.98 ± 0.08	0.84 ± 0.07	8.91 ± 3.49	−4.90 ± 1.25	1.15 ± 0.29	0.13 ± 0.02	−0.15 ± 0.02	1.14 ± 0.14	0.52 ± 0.20*
		Cont	0.87 ± 0.10	1.41 ± 0.25	0.98 ± 0.07	0.82 ± 0.05	11.42 ± 3.22	−6.76 ± 1.27	2.67 ± 1.16	0.21 ± 0.04	−0.13 ± 0.02	1.27 ± 0.18	0.75 ± 0.16*
	UKAD	Ipsi	0.99 ± 0.16	1.27 ± 0.16	0.96 ± 0.05	0.83 ± 0.05	8.76 ± 3.05	−4.99 ± 1.00	1.23 ± 0.21	0.15 ± 0.02	−0.13 ± 0.02	1.03 ± 0.29	0.50 ± 0.06
		Cont	0.86 ± 0.10	1.43 ± 0.19	0.98 ± 0.05	0.81 ± 0.04	11.11 ± 2.61	−6.11 ± 1.02	2.31 ± 0.95	0.19 ± 0.03	−0.13 ± 0.03	1.13 ± 0.18	0.63 ± 0.18

Table 3
Symmetry Index (Mean ± SD) based on kinetics during level walking, ramp and stair descent for conventional UKA and ACL-deficient UKA groups. Reported are stance time (T), first peak (Max_1), second peak (Max_2), local minimum (Min), loading rate (L_r) and unloading rate (U_r). Loading rate and unloading rate were defined as a straight line through 80% of first peak or second peak respectively, according to Stüssi and Debrunner [39]. Positive values = higher for ipsilateral side, negative values = lower for ipsilateral side, ** asymmetry.

Motion Tasks	Group	T	Max_1	Max_2	Min	L_r	U_r
Level Walking	Conventional UKA	0 ± 4	−3 ± 4	−4 ± 2	−1 ± 2	3 ± 18	−8 ± 8
	ACL-deficient UKA	−1 ± 3	−4 ± 2	−3 ± 2	0 ± 3	4 ± 19	−12 ± 6**
Ramp Descent	Conventional UKA	−4 ± 3	−7 ± 6	−2 ± 4	2 ± 3	−37 ± 19	−3 ± 12
	ACL-deficient UKA	−5 ± 4	−6 ± 5	−4 ± 2	0 ± 5	−41 ± 25	−11 ± 15
Stair Descent	Conventional UKA	12 ± 7	−8 ± 13	−1 ± 7	3 ± 5	−28 ± 29	−33 ± 24
	ACL-deficient UKA	14 ± 5**	−11 ± 8	−1 ± 5	1 ± 4	−27 ± 18	−20 ± 25

or the presence of the moving fluoroscope.

Asymmetries in the GRF, measured during level walking, indicate a trend of reduced push off with the implanted side. This could also explain the reduced frontal plane knee moment of the implanted side, though more present in the intact ACL group. Since the asymmetries disappeared with higher walking velocities in the control setting, it may be attributed either to the slow walking velocity or to the presence of the moving fluoroscope. In another study, healthy subjects showed symmetrical peak values of the vertical GRF, with no significant differences during stance phase [48]. In contrast, UKA patients showed increased asymmetry during heel strike in another study [46]. It is important to notice the large SD, especially for loading and unloading rates, across all three motion tasks, showing individual differences of the SI towards either leg. Therefore, no overall asymmetry was observed, indicating no implant specific trend towards the ipsi or contralateral leg.

During downhill walking, the first force peak was increased compared to level walking due to higher impact [43]. However, it was surprising that for the ipsi and contralateral side in both groups the forward propulsion of the body was higher than the decelerating impulse. This is in contrast to the results of Lay et al. showing higher decelerating forces in healthy, due to increased braking forces when walking downhill [43]. The greater acceleration and decreased deceleration of both UKA groups could result from the moderate angle and the short distance of the ramp, causing no particular need for deceleration. Another reason could be the measurement of the GRF right after movement initiation, where acceleration is needed to increase velocity. The UKA group with an intact ACL also showed a reduction in sagittal plane moment during ramp descent in contrast to the ACL-deficient group.

During stair descent, with the highest maximum knee flexion and ground reaction forces, there were no significant differences between the two groups. Another study investigated the kinematics during stair descent between TKA and a matched control group and found significantly lower peak of knee flexion for the TKA group (90.97° vs. 94.05°) [49]. Their results are comparable to our study (conventional UKA: 94.0°, ACL-deficient UKA: 97.3°), particularly indicating that ACL-deficient UKA did not show reduced knee flexion during stair descent, compared to conventional UKA. This is in contrast to TKA when compared against a control group. In a longitudinal evaluation study of stair walking between ACL-intact and ACL-deficient patients, Lepley et al. found no differences for any frontal or sagittal plane joint angles at peak or initial contact [50]. These findings are in line with our hypothesis that ACL-deficient UKA patients show similar function to conventional UKA patients. Nonetheless, a difference in IE rotation during swing phase seems to be detectable especially during stair descent, presenting an increase in internal femoral rotation, peaking in the middle of swing phase [Fig. 2]. This may be explained by a low muscle activity during swing phase, in combination with a missing ACL, resulting in higher IE rotation. However, there was no difference in IE rotation throughout the whole gait cycle.

The force magnitudes of the first peak during stair descent were higher for both groups compared to level walking and ramp descent. This is in accordance with Stacoff et al. showing increased vertical forces for both healthy and UKA when comparing to level walking. This indicates achievability to accept high forces with the UKA operated leg during more demanding activities [46]. The accelerating impulse is higher than the decelerating and over a longer portion of stance phase for ipsi- and contralateral side in both groups, indicating gain in velocity over the three steps, similar to ramp descent.

5. Limitations

The present work has several limitations, especially linked to other aspects of the study. The moving fluoroscope limits gait velocity due to the acceleration limit of the machine. Further, a band was used for the connection of the position sensor to the implanted leg, which may have an influence on the movement pattern. However, Hitz et al. showed, that gait characteristics, when walking with the moving fluoroscope, are comparable to walking at slow velocities. They concluded that evaluating groups both measured with the moving fluoroscope is valid, but care should be taken when comparing the results to subjects walking at self-selected speed without the moving fluoroscope [51]. Additionally, the maximum elevation height of the moving fluoroscope was 1 m and therefore, only three steps were measured during stair descent, which limits the examination to one full gait cycle. For stair descent and ramp descent, the measurement started short after movement initiation, which can result in lower magnitudes of GRF because of reduced velocity, and higher acceleration to gain speed.

Using optical tracking systems, with skin marker related soft-tissue artefacts, is another limitation. The movement of the skin as well as the muscle contraction do not allow an exact tracking of the underlying bone and consequently influences the results.

It is important to notice our small sample size of only ten and eight patients for the conventional UKA and ACL-deficient UKA group respectively. Due to the limited indication for the ACL-deficient UKA group it was not feasible to increase the sample size at this time.

6. Conclusion

The most important finding of this study was that there were no differences in kinematics and kinetics, including knee joint moments, between patients undergoing conventional medial UKA and patients with a medial UKA, presenting ACL deficiency. Overall, more differences were observed in kinetics between the implanted and the contralateral native side, than between the two UKA groups. UKA with a reduction in posterior tibial slope, relative to the native knee, may be an alternative treatment option, for carefully selected patients. It is important to note, that tibial slope reduction intends to compensate for translational instability, while rotational stability of the knee is required for this procedure. Our results indicate good functional outcome of ACL-deficient UKA, however, long-term clinical results are needed to offer specific guidelines for UKA in ACL-deficient patients.

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