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Does Interlimb Knee Symmetry Exist After Unicompartmental Knee Arthroplasty?

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Abstract

Background Unicompartmental knee arthroplasty (UKA) has long been a treatment option for patients with disease limited primarily to one compartment with small, correctable deformities. However, some surgeons presume that normal kinematics of a lateral compartment UKA are difficult to achieve. Furthermore, it is unclear whether UKA restores normal knee kinematics and interlimb symmetry.

Questions/purposes We determined knee kinematics exhibited during stair ascent by patients with medial- (MED-UKA) or lateral-UKA (LAT-UKA) and if the knee kinematics of the operated and nonoperated limbs were symmetrical.

Methods Participants were 17 individuals with MED-UKA and nine with LAT-UKA, all with nondiseased contralateral limbs. For each limb, participants walked up four stairs for five trials while a motion-capture system obtained reflective marker locations. Temporal events were determined by force platform signals. Interlimb symmetry was classified for temporal gait and knee angular kinematics by comparing observed interlimb differences with clinically meaningful differences set at 5% of stride time for temporal variables and 5° for angular variables. The minimum postoperative followup was 6 months (median, 24 months; range, 6–53 months).

Results Neither group demonstrated clinically meaningful mean interlimb differences. However, approximately half of participants of each UKA group displayed asymmetry favoring the operative or nonoperative limb with similar frequency.

Conclusions Many patients undergoing UKA demonstrate kinematic interlimb symmetry during stair ascent. Interlimb asymmetry may be affected by a variety of factors unrelated to the UKA.

Clinical Relevance A MED- or LAT-UKA can potentially restore normal knee function for a demanding task of daily life.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
Patients were recruited from Athens Orthopedic Clinic, Athens, GA, USA, and data collection was performed at the Biomechanics Laboratory at the University of Georgia, Athens, GA, USA.

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Introduction

Use of unicompartmental knee arthroplasty (UKA) has increased considerably in recent decades as a result of improved implant technology and surgical techniques [3, 28]. It has been suggested that UKA should result in a more normal restoration of knee function compared with TKA because the procedure requires less soft tissue dissection and both cruciate ligaments are preserved [7, 14]. However, studies on survival rates and clinical measures (eg, Knee Society scores) of UKA demonstrate mixed results [3, 12, 15, 28, 30], and some evidence of early failure rates has been reported [21]. Therefore, some surgeons are reluctant to use this procedure as a result of conflicting evidence of effectiveness [3, 12, 15, 28, 30].

Biomechanical findings for individuals with UKA also display mixed results [1, 6, 11, 24, 31]. For UKA knee kinematics generated from radiography or fluoroscopy [1, 6, 24], it has been reported that satisfactory knee kinematics are displayed compared with TKA or healthy knees. However, Akizuki et al. [1] observed that kinematic patterns were not consistent among patients and interparticipant variability was high.

Other investigators have explored UKA knee kinematics of level walking using motion-capture methodology [11, 31]. Fuchs et al. [11] reported that patients undergoing UKA were able to achieve maximum knee flexion/extension angles similar to healthy control subjects. On the other hand, Webster et al. [31] noted that patients undergoing UKA versus control subjects displayed different knee flexion angles at initial contact and maximum extension during the stance phase. These two studies listed focused primarily on patients with UKA of the medial compartment (MED-UKA), whose knee kinematics may vary from those of patients with a lateral compartment UKA (LAT-UKA).

Understanding the knee motions of patients undergoing UKA during the performance of real-life activities that occur repetitively during patients' daily lives can provide insight into UKA knee mechanics. One such activity, stair ascent, is a very common activity yet very muscularly demanding [29]. Thus, we believe it is an excellent movement for functional evaluation of a lower-limb UKA [4]. Weinstein et al. [32] found individuals with an UKA displayed a reduced range of knee flexion compared with healthy individuals during stair ascent, although a wide range of interparticipant variation of other kinematic variables also was displayed. However, implant technology and surgical procedures have changed since this seminal study was published (1986). Moreover, there is a lack of understanding of the external knee kinematics, especially for internal/external rotation and abduction/adduction for current UKA designs. Additionally, we know much less about the biomechanics of individuals undergoing LAT-UKA compared with MED-UKA.

Gait symmetry/asymmetry is a common clinical indicator of lower limb function during locomotion [22]. Asymmetrical interlimb kinematics displayed during locomotion have been associated with pathological gait [36]. Knee abduction/adduction kinematics of an UKA limb have been correlated with mechanical wear on arthroplasty components [32]. Thus, greater adduction or abduction motion of the UKA compared with the non-UKA limb may indirectly indicate excessive loading on the contact surface of one of the tibiofemoral compartments. Consequently, such abnormal loading would potentially exacerbate osteoarthritis progression on the intact compartment or wear on the UKA component [22, 32]. We presume that, as a result of keeping more ligaments intact and damaging less tissue during an UKA than a TKA, interlimb symmetry would be displayed by patients who had an UKA with a normal contralateral limb.

The purposes of this study, therefore, were (1) to determine if groups of patients with MED-UKA or LAT-UKA with a nondiseased contralateral limb would display interlimb symmetry during stair ascent; (2) to evaluate interparticipant variation of interlimb kinematic differences with reference to clinically meaningful difference criteria; and (3) to report stair kinematics performed by patients with UKA.

Materials and Methods

Twenty-six healthy patients who had a MED-UKA (n = 17) or LAT-UKA (n = 9) at least 6 months earlier (median postoperative time, 24 months; range, 6–53 months) [17], nondiseased contralateral limbs, and no other musculoskeletal disabilities were recruited for the study to date (Table 1). The condition of the contralateral knee was diagnosed as clinically healthy using standard radiographs. All participants provided written informed consent as approved by the human subjects institutional review board of all institutions involved. Among recruited participants, 14 MED-UKA and six LAT-UKA knees had an iBalance Unicondylar Knee® (Arthrex, Naples, FL, USA) and three MED-UKA and three LAT-UKA knees had a Zimmer Unicompartmental High Flex Knee System® (Zimmer, Warsaw, IN, USA) implant. Both devices are FDA-approved. Potential participants who had another implant in any lower limb joint or a medical condition or disease that potentially could affect their performance or health were excluded from this study. The preoperative deformities of both groups were similar. The average mechanical deformity in the MED-UKA group was 4° varus (range, 0°–7°) with 65% of the group displaying

Table 1. Demographics of participants

UKA group	Number	Age (years)	Sex	Height (cm)	Mass (kg)	Postoperative time (months)
Medial	17	68.0 ± 7.4	Male: 6; female: 11	162.7 ± 7.1	74.1 ± 12.3	24.4 (8–53)
Lateral	9	63.1 ± 7.8	Male: 3; female: 6	167.2 ± 6.4	71.1 ± 13.3	27 (6–50)

Values shown are means ± SD. Ranges for postoperative time are shown in parentheses; UKA = unicompartmental knee arthroplasty.

fixed deformities (deep medial collateral ligament released). The LAT-UKA group had an average of 5° valgus (range, 0°–10°) with 33% of these participants having fixed deformities (iliotibial tract released).

We plan a complete study for a total of 40 participants, 20 in each UKA group; this final sample size will provide 84% power to detect a clinically meaningful difference of 5° between limbs for knee abduction or adduction angular displacement within each UKA group using a paired t-test assuming two-sided alpha = 0.05, interlimb correlation of 0.6, and a pooled SD of 8° based on pilot data. With the numbers available at the time of this preliminary analysis (n = 17 LAT-UKA and n = 9 MED-UKA), the power to detect these differences was less than 80% for many variables. Consequently, a descriptive approach of interlimb differences using 95% confidence intervals and individual participant analyses of interlimb symmetry/asymmetry was warranted. We defined interlimb symmetry for a given variable to be an interlimb difference of less than 5% of stride time for temporal variables and less than 5° for angular quantities.

All surgery was performed by one surgeon (OMM). The medial reconstructions were exposed through a limited subvastus approach, whereas the lateral cases were exposed through a limited lateral parapatellar arthrotomy. Each patient underwent a tibia-first reconstruction technique with a neutral to slightly undercorrected (0°–2°) mechanical axis as the desired alignment target. Soft tissue releases were performed as needed to restore a near neutral postoperative mechanical axis. After establishment of the desired extension space, spacers were used to determine the appropriate femoral component size and posterior condylar resection required to achieve a well-balanced reconstruction. Preexisting tibial slope was maintained. All patients were treated with the same postoperative therapy protocol that included immediate weightbearing and active ROM exercises.

All testing was performed in a biomechanics laboratory. Anthropometric characteristics were obtained. Following the method of Cappozzo et al. [8], 36 reflective markers (14 mm diameter), including 30 lower extremity markers, were placed on the participant [18, 19]. An additional six markers were placed on the steps to later identify their spatial locations. The participant completed a warm-up and practiced stair locomotion before collecting data. For the stair ascent task, the participant walked two steps on the ground and then continued to ascend four stairs (height, 20 cm; depth, 28 cm) barefoot at a self-selected speed. Participants performed five successful trials starting with the right limb and five starting with the left. Limb order was counterbalanced. A successful trial occurred if the performer ascended the stairs using a walking-style gait and achieved clean contact with each force plate. Reflective marker locations were recorded by a seven-camera motion capture system (Vicon MX-40®; Vicon, Los Angeles, CA, USA; 120 fps). One force platform (AMTI™ OR6-6-1®; Advanced Mechanical Technology, Inc, Newton, MA, USA), embedded in the floor in front of the first step, and a second platform (FP4060-NC®; Bertec®, Columbus, OH, USA) embedded in the first step were used to measure the vertical ground reaction forces (GRFs) of each foot (1200 Hz). These GRFs were filtered using a fourth-order Butterworth low-pass filter at 100-Hz cutoff frequency and used later to ascertain times of initiation and termination of foot contact. The movement interval of interest was the stride initiated when the foot contacted the first step and ending when the same foot contacted the third step. The foot contact and liftoff events were determined by three continuous timeframes in 6-N increments or decrements in total using vertical GRF. Second foot contact on the third step was detected when the toe marker passed markers attached on the step and was at the lowest vertical position.

Data analysis was performed through author-developed programs written in MATLAB® 7.0 (Mathworks, Inc, Natick, MA, USA). Raw marker coordinate data were smoothed using Woltring's generalized cross-validatory spline smoothing technique [33]. For joint kinematics, the pelvis, thigh, shank, and foot of interest were modeled as rigid segments connected by frictionless joints [18, 20, 34]. Joint angles of the lower extremities of the limb of interest were defined using Cardan angles (rotation sequence = z-y-x, which was flexion[+]/extension, internal[+]/external rotation, and adduction[+]/abduction, respectively) [13]. The lower extremity joint angles exhibited during stair ascent were adjusted to the joint angles displayed during natural standing. Angular displacement variables were defined as follows: extension displacement, adduction displacement, and internal rotation displacement occurring during the stance phase; and flexion displacement, abduction displacement, and external rotation displacement displayed during the swing phase.

For each temporal and angular displacement variable, interlimb difference was calculated as the value of the operated leg minus the value of the unoperated leg. An average between-limb difference was then calculated and a 95% confidence interval for the interlimb difference was constructed from a paired t distribution. Individual participants were classified as symmetric or asymmetric (the absolute value of interlimb difference is less than or greater than, respectively, the relevant clinically meaningful magnitude) for each variable. The frequencies of interlimb symmetry classifications were generated. Clinically meaningful differences were declared as 5° for knee angular displacements and 5% of stride time for temporal variables based on the work of Orishimo et al. [23] and the authors' clinical experience. Analyses were conducted separately for LAT- and MED-UKA groups.

Results

For the UKA group outcomes of the temporal and kinematic variables, the average interlimb difference was not clinically meaningful for any variable among either the MED-UKA or LAT-UKA group (Table 2). Furthermore, 95% confidence intervals for the average interlimb difference excluded clinically meaningful differences for the temporal variables, flexion and extension displacement, and internal and external rotation displacement among the MED-UKA group and for temporal variables among the LAT-UKA group (Table 2).

Many individual participants within each UKA group, however, did display interlimb differences that were clinically meaningful (Table 2). For the temporal variables within the MED- and LAT-UKA groups, four of 17 and two of nine participants, respectively, demonstrated longer stance and swing phases of the operated limb. Conversely, one LAT-UKA participant demonstrated longer stance and swing phases of the nonoperated limb. For the kinematic variables, clinically meaningful interlimb differences were observed for approximately half of the participants of each UKA group; asymmetry, when present, tended to favor the operative or nonoperative limb with similar frequency (Table 2). Five MED-UKA and three LAT-UKA participants exhibited greater angular displacements of the operated compared with the nonoperated limb at least for one axis. Conversely, approximately the same proportion of patients had greater angular displacements of the nonoperated limb for most of the variables. Overall, the proportions of participants displaying interlimb symmetry were qualitatively similar for MED- and LAT-UKA groups. The limb that displayed the higher amount of knee displacement was not UKA group (medial or lateral) -dependent or limb-dependent. Among individual patients, the participants who displayed a clinically meaningful interlimb kinematic difference at one joint during a given ascent phase did not necessarily display differences about the other axes. Only four MED-UKA and three LAT-UKA participants demonstrated clinically meaningful differences for all three axes.

Descriptively, the UKA knee of both groups, on average, displayed displacements of 55° extension (range, 44°–66°), 12° adduction (1°–24°), and 15° internal rotation (5°–24°) during the stance phase, then exhibited 85° of flexion (74°–99°), 18° of abduction (7°–30°), and 23° of external rotation displacement (7°–39°) during the swing phase (Fig. 1). A UKA limb stride was composed of 65% of

Table 2. Means ± SD of interlimb difference scores and lower (LB) and upper bounds (UB) of 95% confidence interval (CI) of interlimb differences (value of operated − nonoperated limb) of medial and lateral UKA groups

Variable	MED-UKA (n = 17)					LAT-UKA (n = 9)				
	Interlimb difference	Frequency		95% CI		Interlimb difference	Frequency		95% CI	
		OP > non-OP	OP < non-OP	LB	UB		OP > non-OP	OP < non-OP	LB	UB
Stance phase (% total stride time)	1 ± 3	4	0	−0.4	2.5	0 ± 3	0	1	−1.9	2.7
Swing phase (% total stride time)	−1 ± 3	3	0	−2.5	0.4	0 ± 3	2	1	−2.7	1.9
Extension displacement (degrees)	−1.5 ± 4.7	3	4	−3.9	0.9	2.4 ± 5.4	3	0	−1.7	6.5
Flexion displacement (degrees)	−1.9 ± 5.9	1	5	−4.9	1.2	1.6 ± 4.7	3	1	−2.0	5.2
Adduction displacement (degrees)	1.7 ± 7.2	5	4	−2.0	5.4	−2.4 ± 5.6	0	4	−6.8	1.9
Abduction displacement (degrees)	0.8 ± 8.2	5	5	−3.4	5.0	−1.7 ± 9.4	2	3	−8.9	5.5
Internal rotation displacement (degrees)	−0.4 ± 4.3	3	2	−2.6	1.8	−1.5 ± 5.5	1	2	−5.7	2.7
External rotation displacement (degrees)	−1.1 ± 6.1	3	5	−4.3	2.1	−3.7 ± 9.4	2	3	−10.9	3.5

The frequency of participants who displayed a clinically meaningful interlimb difference (5% stride time for temporal variables and 5° for angular kinematic variables) is presented by the limb that displayed the greater magnitude; MED-UKA = medial unicompartmental knee arthroplasty; LAT-UKA = lateral unicompartmental knee arthroplasty; OP = operated limb; non-OP = the nonoperated limb.

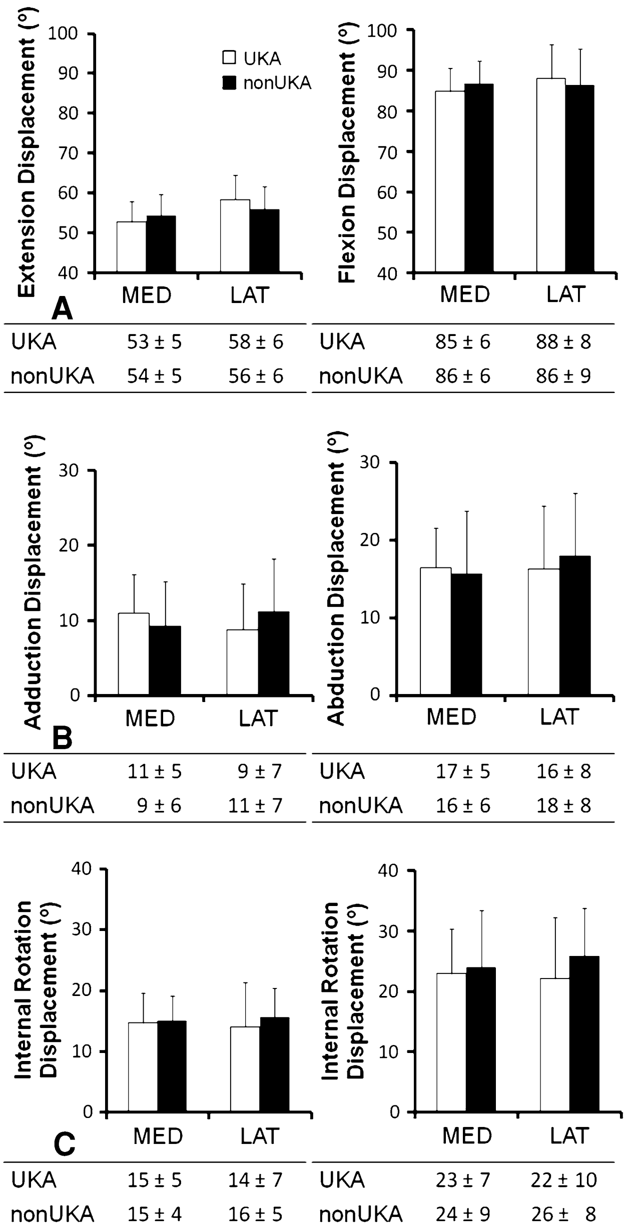

Fig. 1A–C Knee displacements of UKA limb (white) and non-UKA limb (black) are shown on (**A**) sagittal, (**B**) frontal, and (**C**) transverse planes.

Table 3. Means ± SD (range) of the lengths of gait phases relative to total stride time (% stride time) of medial (MED) and lateral (LAT) unicompartmental knee arthroplasty (UKA) participants

UKA group	Limb	Relative time (%)	
		Stance phase	Swing phase
MED	UKA	67.1 ± 2.6 (62–72)	32.9 ± 3.3 (28–38)
	Non-UKA	66.0 ± 2.6 (60–71)	34.0 ± 3.3 (29–40)
LAT	UKA	64.3 ± 2.8 (59–67)	35.7 ± 2.8 (33–41)
	Non-UKA	63.3 ± 2.9 (58–67)	36.1 ± 2.9 (33–42)

stance phase and 35% of swing phase, on average (Table 3; Fig. 2).

Discussion

Compared with the increased interest in and practice of UKA [28], biomechanical knowledge of patients with an UKA is limited, especially for those with a LAT-UKA. Until a larger, more congruent body of evidence of effectiveness exists, some surgeons may remain reluctant to use UKA. Understanding the interlimb kinematics of UKA for a common but functionally demanding task can help establish whether knee motions are similar to nonoperated limbs. We anticipated that, as a result of keeping more ligaments intact and damaging less tissue during an UKA than a TKA, interlimb symmetry would be displayed by both UKA groups on average but that considerable interparticipant variation might exist.

Several limitations of our study are noted. First, our sample size was low, because the data presented here are initial findings of a larger, ongoing study. As a result, we have used a more exploratory approach focusing on confidence intervals and individual-participant outcomes. Second is the use of markers affixed to the skin. Although the true tibiofemoral motions cannot be known using this method, surface motion measurement is acceptable within ± 2° of error using camera-based motion capture systems [16]. This limitation is well recognized in these types of studies but is mitigated by our data reduction methods. Third, we cannot determine whether the knee kinematics after UKA are truly similar to individuals with two healthy knees, because we did not report data from control participants. Fourth, the magnitudes of clinical meaningful differences are not well established in the literature. In the current study, therefore, clinical meaningful differences were set by the authors' clinical experience and the relevant but limited amount of prior literature [23].

Our prediction that interlimb symmetry would be displayed on average by both UKA groups was supported. Qualitatively, the LAT-UKA and MED-UKA group interlimb differences displayed similar outcomes, although confidence intervals for interlimb differences were naturally wider for the smaller (n = 9) LAT-UKA group. Mean interlimb differences were not clinically meaningful for any variable, and 95% confidence intervals that exclude differences of clinically meaningful magnitude furthermore constituted statistical evidence that the true mean difference is probably of less than clinically meaningful magnitude for those variables. However, an interlimb difference for each individual, defined as the value of the operated minus the unoperated leg, could take either a

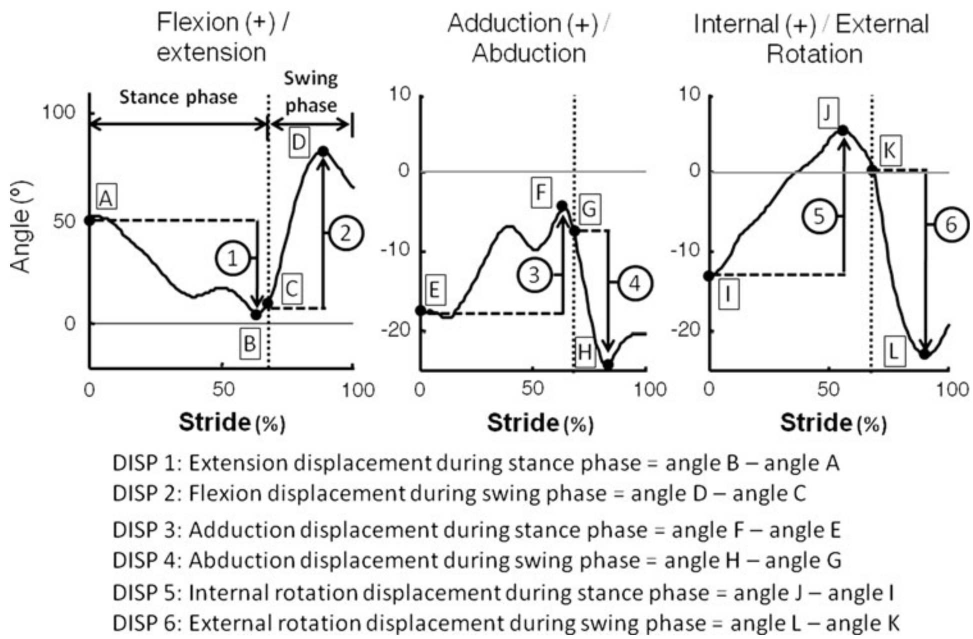

Fig. 2 Knee angles of all components of one trial from a representative participant during the stride of interest (foot contact with the first step to contact with the third step). The vertical dashed line represents the foot-off event. Points A, E, and I = angles at foot contact; B, F, and J = maximum extension, adduction, and internal rotation angle during the stance phase, respectively; C, G, and K = angles at the end of the stance phase; and D, H, and L = maximum flexion, abduction, and external rotation angle during the swing phase, respectively. DISP = displacement.

Table 4. Summary of stair ascent studies of stride velocity and knee joint kinematics of unicompartmental, TKAs, and healthy knees

Study, year	Stair dimensions (height: depth; cm)	Knee type (number)	Stride velocity (cm/s)	Extension displacement (°)	Flexion displacement (°)	Adduction displacement (°)	Abduction displacement (°)	Internal rotation displacement (°)	External rotation displacement (°)
Catani et al. [9], 2003	16:28	TKA (20)	36.2*	–	76*	–	–	–	–
		Healthy (10)	43.3	–	89	–	–	–	–
Costigan et al. [10], 2002	20:30	Healthy (35)†	43.6	**58**‡	**80**	**4**	**3**	**2**	**1**
Protopapadaki et al. [25], 2007	18:28.5	Healthy (33)	49	**50**	**92**				
Reeves et al. [26], 2008	17:28	Healthy (15)	92 (step/min)	**49**	**79**	–	–	–	–
Riener et al. [27], 2002	22.5:25	Healthy (10)	–	**68**	**90**				
Weinstein et al. [32], 1986		MED-UKA (8)	–	–	81ᵃ	–	–	–	–
The current study	20:28	MED-UKA (17)	38.3	53	85	11	17	15	23
		LAT-UKA (9)	36.5	58	88	9	16	14	22

* Average from two different UKA/TKA groups; †underlined: participants are young adults; ‡bold: displacement values of other studies were estimated using angle graphs of group-ensemble averages; MED = medial; UKA = unicompartmental knee arthroplasty; LAT = lateral.

positive or negative value in its departure from zero, depending on which leg was favored; thus, a group average of zero difference could result from a qualitatively wide range of individual interlimb asymmetry if asymmetry favored the operated versus nonoperated limbs with similar frequency.

Examination of the variation between individual participants is more revealing. The majority of patients displayed interlimb symmetry for temporal characteristics, but approximately half displayed some type of interlimb asymmetry for knee angular displacements. There did not appear to be a UKA group effect for this variation. There are several potential explanations for the knee displacement asymmetry. We surmise that several factors such as limb dominance, stair ascent movement technique [26], muscle strength [10, 32], implant placement [32], and knee alignment pre- and postoperatively [23, 32] could have influenced interlimb symmetry more than having had an UKA. Limb dominance and pre- and postoperative knee alignment may have had minimal influence, however, because there was no clear trend for the limb that displayed greater angular displacement. To clarify effects of potentially confounding factors in the study, an informal, a posteriori correlation analysis was performed. Limb dominance and postoperative knee alignment did not correlate with the difference scores of the MED-UKA group (both $r < |0.32|$). For the LAT-UKA group, prealignment appeared to be associated with the difference score for flexion displacement occurring during the swing phase ($r = 0.715$, $p = 0.03$). As a result of the small sample size of the LAT-UKA group, this will need to be confirmed. Weinstein et al. [32] also observed this same phenomenon of interparticipant variation for knee kinematics among patients with a MED-UKA for a stair ascent study. They attributed the interparticipant variability of the joint kinematics with the interparticipant knee moment variation as well as femoral and tibial component positioning.

For our third aim, describing the kinematics of MED-UKA and LAT-UKA limbs, a comparison of our magnitudes and kinematic time patterns with prior literature is provided (Table 4). Akin to the interlimb symmetry outcomes, there is partial support for our prediction of restored UKA limb kinematics. Compared with other literature, our flexion/extension kinematic pattern was similar, and angular displacement magnitudes were within 5°, on average, of those reported for healthy young and older populations (Table 4). In addition, the UKA and non-UKA knee kinematic time patterns of both groups were qualitatively consistent with the patterns of healthy knees described by others [25, 27] for stair ascent (Fig. 1). Conversely, our knee displacement magnitudes and kinematic patterns for the abduction/adduction and internal/external rotation axes were greater than those found by Costigan et al. [10] for stair ascent of healthy young adults. However, their participants were younger and ascended faster. Moreover, because their data came from group ensemble curves, their peak magnitudes likely were attenuated. Based on prior literature, knee kinematics of individuals with an UKA compared with a TKA may be more similar to healthy knees [27, 32]. Although very few comparable studies of patients undergoing TKA during stair ascent exist [9], multiple studies have demonstrated persistent gait asymmetry after TKA during level walking [2, 5, 25, 35]. It is reasonable to expect these asymmetries to persist during this more demanding stair task.

In summary, patients who have had an UKA have the potential to demonstrate satisfactory interlimb symmetry and knee kinematics during stair ascent. Although half of the individual participants displayed clinically meaningful differences, these were not UKA limb-dependent. We therefore conclude that these initial findings for knee kinematics tentatively support the use of this UKA device in achieving successful knee movements in both medial and lateral compartment reconstructions.

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