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# Knee Moments After Unicompartmental Knee Arthroplasty During Stair Ascent

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**Abstract**
*Background* For unicompartmental knee arthroplasty (UKA), abnormal loading on the tibiofemoral joint could exacerbate knee osteoarthritis or implant wear. Joint moments are an indirect measure of such loading. However, little is known about knee moments of patients with UKA, tempering enthusiasm for its use.
*Questions/purposes* In patients with UKAs performing stair ascent, we (1) determined whether interlimb differences for knee moments are demonstrated, (2) described the knee kinetics of patients with medial and lateral UKAs, and (3) investigated possible factors that might influence the knee abductor moments.
*Methods* In our cross-sectional study, we recruited 26 patients with UKA with nondiseased contralateral limbs who performed stair ascent. Seventeen patients had medial UKAs and nine had lateral UKAs. Paired t-tests and CIs were applied to determine interlimb differences within each UKA group for peak knee moments and times to peak moments.
*Results* During stair ascent, the medial UKA group displayed greater peak extensor moments for the nondiseased compared to the UKA limb ($p = 0.030$), whereas the lateral UKA group did not ($p = 0.087$). For both medial and lateral UKA groups, the UKA limb demonstrated greater internal peak abductor moments ($p = 0.005$ and 0.013, respectively). Both UKA groups exhibited knee moments similar to those in the literature. Limb dominance and postoperative time were correlated for both UKA groups.
*Conclusions* Reduced knee extensor moments of limbs with UKA displayed by some participants may indicate less compressive loading on the tibiofemoral joint surfaces,

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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 Athens Orthopedic Clinic and Biomechanics Laboratory at the University of Georgia (Athens, GA, USA).

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whereas the increased abductor moments suggest increased compression on the medial compartment. These findings suggest UKA knees may not be subjected to excessive loads regardless of the side reconstructed.

*Level of Evidence* Level II, therapeutic study. See Instructions for Authors for a complete description of levels of evidence.

## Introduction

With the increased number of individuals who will seek solutions for painful knee osteoarthritis (OA) [17], it is important to have several, evidence-based alternatives available so that the best treatment for a given individual can be selected. Among various treatments for OA, modern unicompartmental knee arthroplasty (UKA) has been considered a good treatment due to improved implant design and minimally invasive surgical techniques [2, 35]. UKA, compared to TKA, entails smaller incisions, less hospital time, more intact soft tissues (eg, cruciate ligaments), and less postoperative pain [13, 32]. Satisfactory UKA knee kinematics have been reported by several investigators [1, 5, 8, 12, 27, 40, 41]. Biomechanically, patients with UKA are able to perform or maintain typical quadriceps mechanism during level walking [8]. These potential benefits encourage some surgeons to utilize UKA [30, 35]; however, concerns remain regarding the risk of early failure due to the loads that these devices may be subjected to, particularly in lateral compartment reconstructions [6, 22].

Excessive knee abductor or adductor moments have been considered one of the major contributors to OA progression [39, 42] and possibly TKA implant wear [7]. For UKAs, greater moments therefore could result in excessive loading of either the implant or the nonoperated joint surfaces, which may potentially increase implant wear or exacerbate OA progression, respectively. Indeed, older studies have demonstrated fairly large abductor moments in some UKAs [41]. However, newer techniques and improved designs may have reduced these potentially adverse biomechanical conditions.

Compressive tibiofemoral loading is also highly correlated with quadriceps muscle force [38]. The knee extensor moment can sometimes be an indirect indicator of quadriceps muscle strength during functional activities [47]. Chassin et al. [8] observed that patients with UKA were able to demonstrate a biphasic extensor/flexor moment pattern similar to those produced by healthy individuals during level walking. Stair ascent is more demanding of knee muscles than gait [37] and an important task often used in daily life. Thus, it is an excellent movement for functional evaluation of a lower-limb UKA [3].

In patients with UKAs performing stair ascent, we therefore (1) determined whether interlimb differences for knee moments are demonstrated, (2) described the knee kinetics of medial and lateral UKAs, and (3) investigated possible factors that might influence the knee abductor moments.

## Patients and Methods

In this cross-sectional study, we recruited 26 healthy patients with at least 6 months of postoperative time, 17 with medial UKAs and nine with lateral UKAs (Table 1; detailed patient characteristics and surgical procedures used are also described in our previous study [11]). The contralateral limbs were diagnosed as disease-free by the orthopaedic surgeon investigator (OMM) using criteria of absence of symptoms, physical examination, and available radiographs. No other musculoskeletal disabilities were self-reported on our laboratory health and medical status questionnaire or visually observed. Twenty patients had an iBalance Unicondylar Knee® implant (Arthrex, Inc, Naples, FL, USA) and six had a Zimmer Unicompartmental High Flex Knee System® implant (Zimmer, Inc, Warsaw, IN, USA). Both devices are FDA-approved. The frequency of participants whose UKA limbs were their dominant limbs was 58.8% and 77.8% in the medial and lateral UKA groups, respectively. Mechanical alignment improved from −4° ± 3° (range, −7° to 0°) preoperatively to −2° ± 2° (range, −6° to 1°) postoperatively in the medial UKA group and from 5° ± 3° (range, 0°–10°) to

**Table 1.** Demographics of participants

| UKA group | Number of participants | Age (years)* | Implant type | Height (cm)* | Mass (kg)* | Leg length (cm)* | Postoperative time (months)† | Mean stride velocity (cm/second) |
|---|---|---|---|---|---|---|---|---|
| Medial | 17 | 68.0 ± 7.4 | Arthrex: 14<br>Zimmer: 3 | 162.7 ± 7.1 | 74.1 ± 12.3 | UKA: 91.9 ± 4.2<br>Non-UKA: 91.5 ± 4.0 | 24.4 (8–53) | 38.3 |
| Lateral | 9 | 63.1 ± 7.8 | Arthrex: 6<br>Zimmer: 3 | 167.2 ± 6.4 | 71.1 ± 13.3 | UKA: 95.0 ± 3.4<br>Non-UKA: 95.4 ± 3.5 | 27 (6–50) | 36.5 |

* Values shown are means ± SD; †values are shown as mean, with range in parentheses; UKA = unicompartmental knee arthroplasty.

1° ± 3° (range, −3° to 5°) in the lateral UKA group. The study was approved by our institutional review board and all participants gave full consent.

We estimated that a sample size of 12 participants would provide greater than 80% power at alpha = 0.05 to detect knee adductor moment interlimb differences of 0.15 (N·m·[body mass · leg length]$^{-1}$) assuming a SD of 0.2 and interlimb correlation of 0.7, based on pilot data of the first five participants and data from a previous TKA gait study [26]. We presumed that our sample size would be sufficient for the medial UKA group but potentially insufficient for the lateral UKA group. Consequently, a descriptive approach of interlimb differences using 95% CIs and individual participant analyses was emphasized to supplement the parametric statistics.

Long-leg radiographs were obtained pre- and postsurgery as part of the patient's standard-of-care treatment procedures. Pre- and postoperative mechanical limb alignments were measured from these uniplanar radiographs at a quiet standing posture with feet in parallel position. Using the radiographs, the mechanical lower-limb alignment of the UKA limb was defined as the angle formed between a line from the center of femoral head (hip center) to the knee center and a line from the knee center to the ankle center [9]. Valgus limb alignment was recorded as positive and varus as negative. Angles were measured using radiograph-measuring software (Cedara I-Research™; Analogic Corp, Peabody, MA, USA). High inter- and intrarater reliability (intraclass correlation coefficients ≥ 0.96 and ≥ 0.97, respectively, with standard error of measurement < 1° for both) have been demonstrated in the measurement of radiographic alignment angles of the lower extremity from long radiographs [36]. Minimal error due to rotational distortion is expected given our positioning protocol and absence of flexion contracture in these patients [45].

Stair ascent tests were performed in a biomechanics laboratory. Thirty reflective markers (14-mm diameter) were placed on the lower extremities of the participant [11, 19, 20]. Anthropometric characteristics, including height, weight, and leg length of both limbs, were measured [43]. Limb dominance was determined by observing the limb used to kick a ball. For the stair ascent task, the participant walked barefoot two steps on the walkway in front of the stairs and then up the stairs (height: 20 cm; depth: 28 cm) at a self-selected speed. Participants performed a total of 10 successful trials starting with either the right or left limb. A trial was deemed successful if the participant climbed the steps continuously and placed only one foot on each step. Limb order was counterbalanced. Marker locations were recorded by a seven-camera motion capture system (Vicon MX-40®; Vicon, Los Angeles, CA, USA; 120 fps). One force platform (OR6-6-1®; Advanced Mechanical Technology, Inc, Newton, MA, USA) embedded in the floor and a second platform (FP4060-NC®; Bertec Corp, Columbus, OH, USA) embedded in the first step were used to obtain the ground reaction force (GRF) signals at 1200 Hz. These GRF signals were used later to ascertain the timing of the stance phase on the first stair and generate joint moments.

Raw marker coordinate data were smoothed using Woltring's generalized cross-validatory spline [44]. Joint angles of the lower extremities were defined using Cardan angles [14]. The lower-extremity joint angles exhibited during stair ascent were adjusted to the joint angles displayed during natural standing. Detailed descriptions of kinematics analysis were stated in the previous study [11].

To generate the internal knee moments occurring during the stance phase, inverse dynamics procedures were performed using author-developed programs written in MATLAB® 7.0 (Mathworks, Inc, Natick, MA, USA). For a trial of a given limb, the lower-extremity segments, including pelvis, thigh, shank, and foot, were modeled as rigid segments connected by frictionless joints [21]. We used the anthropometric data of Dempster as summarized in Winter [43]. A fourth-order, low-pass Butterworth filter (cutoff frequency = 100 Hz) was applied to the GRF and moment signals. Joint moments were aligned with segment axes as defined by International Society of Biomechanics recommendations [46] and were scaled by body mass and leg length.

During visual inspection of the joint moment patterns, it was observed that two different moment-time patterns were displayed by both limbs within both UKA groups [8]. Therefore, knee moment variables that were common to all patterns were analyzed: peak knee extensor moment at early stance phase, peak abductor and external rotator moment during late stance phase, and times to those peak moments (Fig. 1).

Paired t-tests were used to test interlimb differences within each UKA group (alpha = 0.05), and 95% CIs of difference scores (value of the UKA minus the value of the non-UKA limb) were generated. All analyses were conducted separately for the medial and lateral UKA groups. Pearson's correlations were performed to investigate the relationship between peak abductor moments and age, sex, limb dominance, UKA limb length, postoperative duration, and pre- and postoperative alignment of the UKA limb. For the limb dominance variable, a value of 1 was assigned if the UKA limb was the dominant limb; otherwise, a value of 0 was assigned; thus, correlation analysis could be applied. For sex, a value of 1 was assigned for female and a value of 0 for male. Statistical analyses were performed with IBM® SPSS® Statistics software (Version 21.0; IBM Corp, Armonk, NY, USA).

## Results

Group differences for peak joint moment magnitudes were observed for peak knee extensor and abductor moments

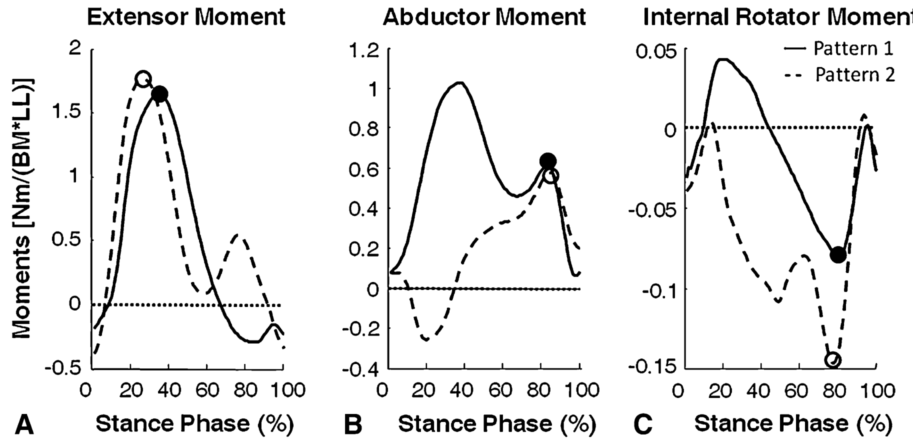


**Fig. 1A–C** Two representative knee moment patterns are displayed by the two groups in (**A**) extensor moment, (**B**) abductor moment, and (**C**) internal rotator moment during stair ascent. Dots indicate peak moments tested. BM = body mass; LL = leg length.

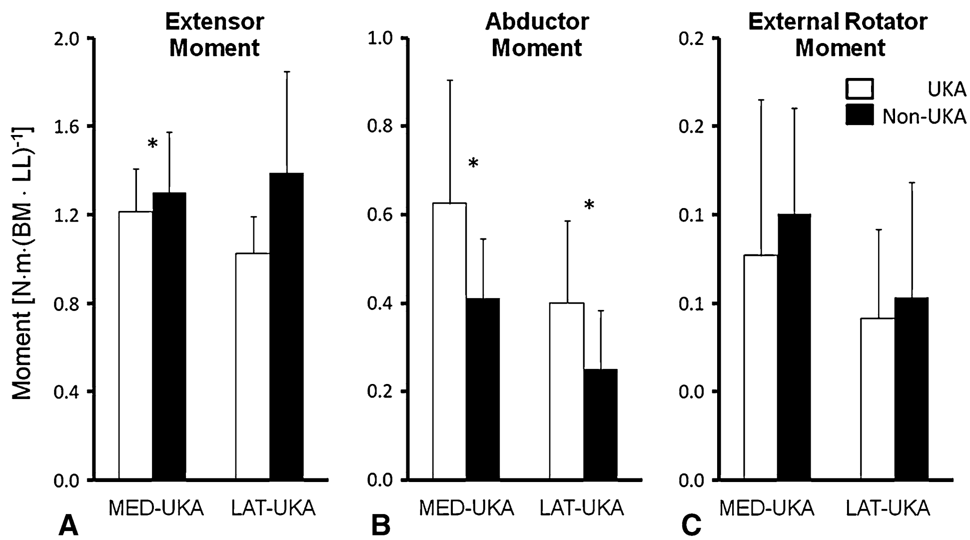


**Fig. 2A–C** Graphs show peak knee moments of UKA and non-UKA limbs for the medial (MED) and lateral (LAT) UKA groups during stair ascent: (**A**) extensor moment, (**B**) abductor moment, and (**C**) external rotator moment. Asterisks indicate significant interlimb differences within a group ($p < 0.05$, paired t-test). BM = body mass; LL = leg length.

(Fig. 2). Patients with medial UKA exhibited significantly less peak knee extensor moments for the UKA limb than for the non-UKA limb (Table 2). The same tendency was displayed by the patients with lateral UKA, although with the number of participants available, this was not significant, and so this finding must be interpreted cautiously ($p = 0.087$; Fig. 2). Both UKA groups exhibited a significantly greater peak abductor moment for the UKA limb than for the non-UKA limb (Table 2). No other group differences were found.

Descriptively, both UKA groups displayed similar knee moment-time patterns. However, within both groups, two distinct patterns of joint moments were observed for both limbs for all three directions (Fig. 1). For both knee moment patterns of the sagittal plane, the knee moment displayed an eccentric flexion moment during the initial stance phase and then concentric extension moments until 50% of the stance phase. Next, the patterns diverged until approximately the last 90% of the stance phase: Pattern 1 displayed a concentric flexion moment, whereas, for Pattern 2, a burst of concentric extension moment was produced. On average, the peak magnitudes common to all patterns for the extensor, abductor, and external rotator moments occurred around 30%, 70%, and 80% of stance phase, respectively, for both limbs and groups. Eleven to 13 patients with medial UKA and five to six patients with lateral UKA demonstrated Pattern 1; the remaining patients demonstrated Pattern 2 for both limbs in all directions. Not all patients demonstrated the same pattern for all directions.

Several factors were associated with the peak knee abductor moments (Table 3). Among the anthropometric and clinical variables, limb dominance (medial and lateral UKAs, respectively: $r = 0.770$ and 0.710; $p = 0.0003$ and 0.032) and postoperative time (medial and lateral UKAs, respectively: $r = 0.651$ and $-0.681$; $p = 0.005$ and 0.043) were correlated with the peak knee abductor moments. In the lateral UKA group, the peak abductor moment also was positively correlated with patient age (Table 3). However, the correlations for postoperative alignment were not significant (medial and lateral UKAs, respectively: $r = -0.084$ and 0.321; $p = 0.748$ and 0.400) (Fig. 3).

**Table 2.** Interlimb difference scores for peak knee moment magnitudes and times to those peaks

| Variable | Medial UKA (n = 17) | | | | Lateral UKA (n = 9) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Lower bound | Upper bound | p value | Mean | Lower bound | Upper bound | p value |
| Extensor moment (N·m·[body mass · leg length]$^{-1}$) | −0.08 | −0.16 | −0.01 | 0.030* | −0.36 | −0.79 | 0.07 | 0.087 |
| Abductor moment (N·m·[body mass · leg length]$^{-1}$) | 0.22 | 0.08 | 0.36 | 0.005* | 0.15 | 0.04 | 0.26 | 0.013* |
| External rotator moment (N·m·[body mass · leg length]$^{-1}$) | −0.02 | −0.06 | 0.02 | 0.298 | −0.01 | −0.04 | 0.02 | 0.471 |
| Time to peak extensor (% of stance phase) | −0.06 | −1.58 | 1.47 | −0.937 | 0.32 | −3.16 | 3.79 | 0.840 |
| Time to peak abductor (% of stance phase) | 0.70 | −5.82 | 7.22 | 0.823 | −11.99 | −25.33 | 1.36 | 0.072 |
| Time to peak external rotator (% of stance phase) | −1.42 | −6.77 | 3.93 | 0.581 | −3.30 | −9.64 | 3.03 | 0.263 |

* Significant difference ($p < 0.05$, paired t-test); a positive or negative value indicates the UKA limb was greater or lesser, respectively, than the non-UKA limb; UKA = unicompartmental knee arthroplasty.

**Table 3.** Correlations (Pearson's r) between peak abductor moments of the UKA limb and anthropometric/clinical characteristics

| UKA group | r value (p value) between peak abductor moments and: | | | | | | |
|---|---|---|---|---|---|---|---|
| | Age | UKA limb length | Sex* | Limb dominance† | Postoperative time | Preoperative alignment‡ | Postoperative alignment‡ |
| Medial | 0.124 (0.635) | 0.259 (0.315) | −0.046 (0.860) | 0.770 (0.001) | 0.651 (0.005) | 0.168 (0.520) | −0.084 (0.748) |
| Lateral | 0.713 (0.031) | −0.289 (0.451) | 0.262 (0.496) | 0.710 (0.032) | −0.681 (0.043) | −0.012 (0.975) | 0.321 (0.400) |

* Positive number indicates moment is correlated to female population (female = 1; male = 0); †positive number indicates moment is correlated to the condition when the UKA limb was the dominant limb (UKA limb dominant = 1; UKA limb not dominant = 0); ‡mechanical alignment measured from long-leg radiographs; varus angles were recorded as negative values and valgus angles as positive values; UKA = unicompartmental knee arthroplasty.

## Discussion

Although interest in utilizing UKA has increased in recent decades [30, 35], the biomechanics of patients with UKAs have been poorly described, especially for those with lateral UKAs and for locomotor movements more strenuous than gait. Stair ascent requires high magnitudes of knee extensor abductor/adductor moments to raise the body and provide mediolateral stability, respectively. Hence, comparing how UKA and non-UKA limbs generate moments during stair ascent can help establish indirectly whether knee loads are similar to those in healthy limbs. In patients with UKAs performing stair ascent, we therefore (1) determined whether interlimb differences for knee moments were demonstrated, (2) described the knee kinetics of medial and lateral UKAs, and (3) investigated possible factors that could influence the knee abductor moments. We found: (1) the UKA limb displayed lesser peak knee extensor moments (for the medial UKA group) and greater late-stance peak knee abductor moments than the non-UKA limb; (2) knee moment patterns of UKA limbs were similar to non-UKA limbs, but two distinct patterns emerged that were displayed by either limb within each UKA group; and (3) knee abductor moments were related to postoperative time and limb dominance.

There were several limitations to our study. First was the low sample size of the lateral UKA group. Numbers of these patients are limited in comparison to the number of patients presenting with isolated medial compartment disease. Second, caution is warranted when comparing our moment magnitudes to those of other studies, as values are sensitive to stair dimensions and participants' characteristics. Third, other factors not measured, for example, leg strength, may have influenced the outcomes. Fourth, a second model of implant was used for three participants in each UKA group. However, the values of these participants appeared within the range of participants with the first implant type and both devices were similar in terms of designed motion arcs and implantation techniques.

For interlimb differences, UKA patients exhibited only two kinetic interlimb differences (Fig. 2). The CIs supported that those differences were likely meaningful (Table 2). For knee extensor moments, it is possible that the lower extensor moment value of the UKA limbs compared to the non-UKA limbs may be related to either deficits in knee extensor strength or shifting body weight more toward the non-UKA limb during the early stance phase. The reduced extensor moment of the UKA limb, though, may be beneficial to compressive loading, as the quadriceps muscles contribute greatly to tibiofemoral compressive loading [38]. For abductor moments, greater

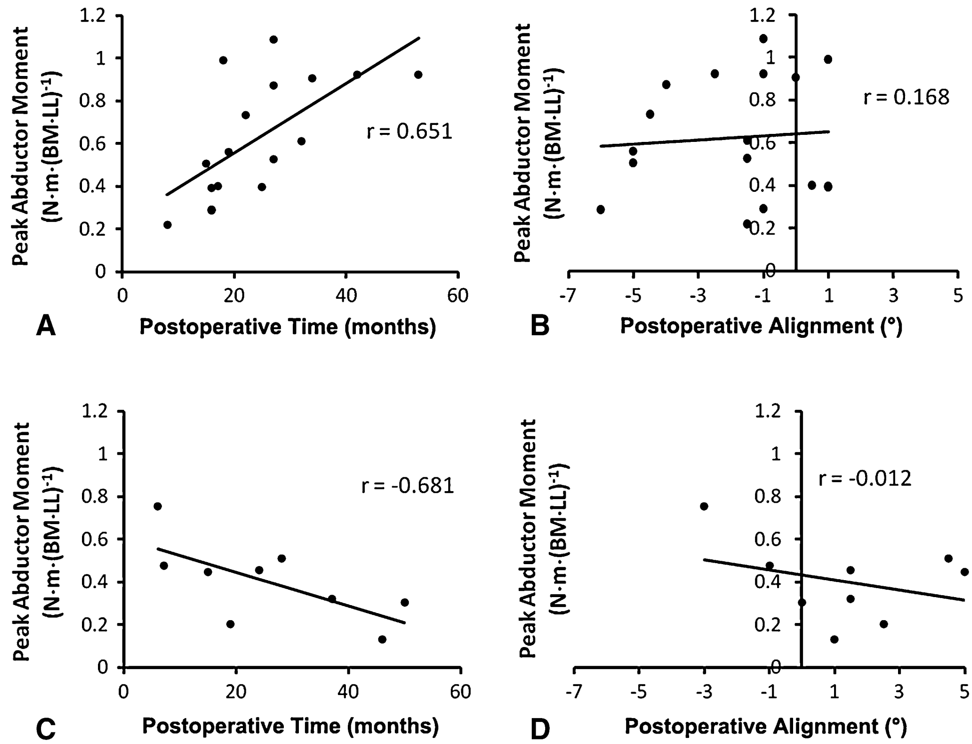


**Fig. 3A–D** Scatter plots compare peak abductor moments during stair ascent to (**A**, **C**) postoperative time and (**B**, **D**) postoperative mechanical alignment (valgus = positive) in the (**A**, **B**) medial and (**C**, **D**) lateral UKA groups. Regression lines and Pearson's correlation r are noted in all graphs. BM = body mass; LL = leg length.

UKA versus non-UKA limb values for both groups may be related to reasons similar to the knee extensor moment explanations found in the literature. First, the UKA limbs may have persistent deficits in knee extensor strength as a result of chronic arthritis [33], although this is not known from our data. As decreased knee extensor strength after TKA has been reported [33], it also may be true in a UKA population. Second, if individuals with UKA were protecting their surgical limb by leaning the body to the nondiseased limb, then greater abductor moments would be required during late stance phase, due to shifting the body more toward to the non-UKA side. A similar strategy has been noted during level walking for patients with OA [16]. Clinically, a greater abductor moment likely places more compressive loading on the medial than the lateral compartment structures [39, 42]. Thus, risk for OA progression or implant wear may be of concern for the medial and lateral UKA groups, respectively [15, 16, 23].

Descriptively, patients with UKA have the potential to demonstrate more normal knee function and less quadriceps avoidance than that seen in TKA populations [4]. For peak joint moment magnitudes, values of both limbs in our study were within the range of values reported for young and healthy older adults [10, 18, 29, 31] (Table 4). Patients with UKA, regardless of limb or operated compartment, also demonstrated moment patterns typical of those reported in the literature [10, 18, 24, 25, 28, 29, 31]. We believe that the two joint moment patterns displayed for each axis are not atypical, as they have been observed in other stair ascent studies of healthy, younger (Pattern 1) and older (Pattern 2) adults [10, 18, 24, 25, 28, 29, 31]. The presence of Pattern 2 has been attributed to lack of muscle strength in older populations [8, 29]. Thus, it is likely that the different patterns are more related to participant age than having had a UKA.

Among the factors associated with the peak knee abductor moments, it is interesting that patients with medial UKAs exhibited increased peak abductor moments with longer postoperative time, but patients with lateral UKAs exhibited the opposite (Fig. 3). For the medial UKA group, the positive relationship indicates that loading increased on the implant component of the UKA limb with increased postoperative time. For the lateral UKA group, the negative relationship may also indicate that loading shifted toward the implant compartment of the UKA limb with increased postoperative time. Thus, these findings in our cross-sectional indicate that, with increased postoperative time, both groups might tend toward having more loading on the implant compartment. Higher abductor moment values were associated with the dominant limb. The non-UKA limb was likely the preferred limb to bear weight on in daily life, as we classified the limb used to kick a ball as the dominant limb [34]. Thus, if the person bore more weight on the nondominant, that is, non-UKA, limb during the stair ascent task, then less UKA limb extensor moment would be required to raise the body. Additionally, a greater peak abductor moment would be needed, due to shifting the body more toward the non-UKA side.

**Table 4.** Summary of stair ascent studies of peak knee moments of UKA, TKA, and healthy knees

| Study | Stair dimensions (height:depth) (cm) | Population (age description; number of knees) | Unit | Extensor moment* | Abductor moment* | External rotator moment* |
|---|---|---|---|---|---|---|
| Costigan et al. [10] (2002) | 20:30 | Young (35) | N·m/kg | 1.16 ± 0.24 | 0.42 ± 0.15 | 0.10 ± 0.04 |
| Lin et al. [18] (2005) | 18:46 | Young (10) | N·m/(kg·LL) | 1.69 ± 0.25 | 0.37 ± 0.13 | 0.08 ± 0.06 |
| Nadeau et al. [24] (2003) | 17:26 | Old (11) | N·m/kg | 0.98 ± 0.18 | 0.78 ± 0.16 | |
| Novak et al. [25] (2011) | 15:26 | Young (30) | N·m/kg | 1.02 ± 0.20 | 0.19 ± 0.07 | |
| | | Old (33) | N·m/kg | 0.99 ± 0.21 | 0.23 ± 0.06 | |
| Reeves et al. [29] (2009) | 17:28 | Old (15) | N·m/kg | 0.89 ± 0.22 | | |
| Riener et al. [31] (2002) | 22.5:25 | Young (10) | N·m/kg | 1.18† | | |
| Current study | 20:28 | Old (17) (medial) | N·m/(kg·LL) | 1.21 ± 0.19 | 0.63 ± 0.28 | 0.10 ± 0.07 |
| | | Old (9) (lateral) | N·m/(kg·LL) | 1.02 ± 0.17 | 0.40 ± 0.19 | 0.07 ± 0.04 |

* Values are expressed as mean ± SD; †moment values of the study were estimated using moment graph of group-ensemble averages; UKA = unicompartmental knee arthroplasty; LL = leg length.

We believe that reduced knee extensor moments of the UKA limb may result in less compressive loading on the tibiofemoral joint surfaces, whereas the increased abductor moments suggest increased compression on the medial compartment. For some individuals, decreased knee extensor moments may be beneficial in minimizing compression during the early stance phase, but greater knee abductor moments likely increased loading during late stance. However, as our joint moment values are comparable to those observed in prior literature, we suggest that UKA knees may not be subjected to excessive loads regardless of the side reconstructed. Based on our observations, it appears that patients with either medial or lateral UKAs maintain some protective gait adaptations, potentially reducing implant loads and interface stresses. We see no basis for restricting the use of these devices to the medial compartment only.

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